## DEVELOPMENT OF AN EXPERT SYSTEM BASED ON THE SYSTEMATIC APPROACH TO TROPICAL CYCLONE TRACK FORECASTING

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**Sponsor: Office of Naval Research**

**OBJECTIVE:** The long-term goals of this project, which is being pursued in collaboration with R.L. Elsberry, are the same as those for the related project entitled, "Systematic Approach to Tropical Cyclone (TC) Track Forecasting," summarized elsewhere. The specific objectives of this project are to conduct exploratory research to: (1) develop a prototype expert system that is based on the systematic approach concept, and which methodically leads the TC forecaster through a sound forecast formulation process, exposes the forecaster to key information, prompts and assists the forecaster to make pivotal decisions, and accomplishes basic tasks for the forecaster wherever feasible and (2) demonstrate the feasibility of such an expert system for improving the accuracy and meteorological utility of official tropical cyclone track forecasts.

**SUMMARY:** This project is a continuation of work started in mid-1996. The emphasis of this project in 1997 was to develop that part of the expert system that assists the forecaster in understanding and characterizing the meteorological environment that is affecting the current motion of the TC. Because TC interaction (TCI) occurs frequently and in various ways in the western North Pacific, considerable effort was devoted to developing a objective algorithm that alerts the forecaster to the possible occurrence of TCI based on analysis of recent motion of TC pairs. A technique for evaluating the accuracy of the numerical model analysis, on which the characterization of the TC environment must be heavily based, has also been developed and transformed into a module of the expert system. Code has been written to assist, but not limit, the forecaster in characterizing the environment of the TC in terms of a pattern, region, and any mechanisms acting to change the environment. Finally, a condensed and updated version of the meteorological knowledge base on the systematic approach has been prepared in the form of a technical report, that will eventually be converted into the help/training module of the expert system.

**PUBLICATIONS:**

Carr, L.E., III and Elsberry, R.L., "Objective Diagnosis of Binary Tropical Cyclone Interactions for the Western North Pacific Basin," *Monthly Weather Review*, 1998, in press.

Carr, L. E., III, Elsberry, R.L., and Boothe, M.A., "Condensed and Updated Version of the Systematic Approach Meteorological Knowledge Base—Western North Pacific," Naval Postgraduate School Technical Report, NPS-MR-98-002, December 1997.

Peak, J.E., Carr, L.E., III, and Elsberry, R.L., "Systematic Approach to Tropical Cyclone Forecasting: Development of a Prototype Expert System," *Preprints, 22nd Conference on Hurricanes and Tropical Meteorology*, pp. 465-466, Fort Collins, CO, American Meteorological Society, Boston, MA, 1997.

**CONFERENCE PRESENTATIONS:**

Carr, L.E., III, Peak, J.E., and Elsberry, R.L., "A Prototype Expert System for the Systematic Approach, USPACOM Tropical Cyclone Conference, Tokyo, Japan, 25-28 February 1997.

Carr, L.E., III, Elsberry, R.L., and Boothe, M.A., "Development of a Systematic and Integrated Approach to Tropical Cyclone Track Forecasting," Interdepartmental Hurricane Conference, Miami, FL, 25-28 March 1997.

Peak, J.E., Carr, L.E., III, and Elsberry, R.L., "Systematic Approach to Tropical Cyclone Forecasting: Development of a Prototype Expert System," 22nd Conference on Hurricanes and Tropical Meteorology, Fort Collins, CO, 19-23 May 1997.

**DoD KEY TECHNOLOGY AREA:** Battlespace Environments

**KEYWORDS:** Tropical Cyclone Prediction, Expert Systems

## APPLICATIONS OF THE SYSTEMATIC APPROACH TO TROPICAL CYCLONE TRACK FORECASTING IN THE WESTERN NORTH PACIFIC AND EXTENSIONS TO OTHER TROPICAL CYCLONE REGIONS

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**Russell L. Elsberry, Distinguished Professor**
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**Sponsor: Space and Naval Warfare Systems Command**

**OBJECTIVE:** Whereas the project entitled, Systematic Approach to the Tropical Cyclone Track Forecasting, has to do with the formulation of the overall systematic approach to tropical cyclone forecasting "concept," particularly the development of a comprehensive meteorological knowledge base to explain tropical cyclone motion in the western North Pacific. The emphasis of this project is the development of specific forecasting tools, as well as the extension the systematic approach concept to other regions of the world where tropical cyclones form.

**SUMMARY:** The first extension of the systematic approach has been to the eastern and central North Pacific. A database of 135 tropical cyclones during 1990-1996 has been classified by using a small set of only four synoptic patterns, three of which are much like their counterparts in the western North Pacific. The fourth pattern accounts for the formation of deep upper level lows in the eastern and central North Pacific, which are not observed in the western North Pacific. In addition, a statistical post-processor is being developed that objectively modifies tropical cyclone (TC) track forecasts made by the Navy Operational Global Atmospheric Prediction System (NOGAPS) to account for the error bias expected when the current environment of the TC conforms to a particular pattern/region combination. In a collaborative effort with the Australian Bureau of Meteorology, the meteorological knowledge base of the systematic approach, which was initially developed to explain TC motion in the western North Pacific, has been adapted to provide dynamically based explanations for TC motion in both the South Pacific and South Indian Ocean regions.

**PUBLICATIONS:**

Bannister, A.J., Boothe, M.A., Carr, L.E., III, and Elsberry, R.L., "Southern Hemisphere Application of the Systematic Approach to Tropical Cyclone Track Forecasting. Part I: Environmental Structure Characteristics," Naval Postgraduate School Technical Report, NPS-MR-97-001, December 1997.

Boothe, M.A., Carr, L.E., III, and Elsberry, R.L., "Extension of the Systematic Approach to Tropical Cyclone Track Forecasting in the Eastern and Central Pacific," *Preprints, 22nd Conference on Hurricanes and Tropical Meteorology*, pp. 467-468, Fort Collins, CO, American, Meteorology Society, Boston, MA, 1997.

**CONFERENCE PRESENTATIONS:**

Boothe, M.A., Carr, L.E., III, and Elsberry, R.L., "Extension of the Systematic Approach to Tropical Cyclone Track Forecasting in the Eastern and Central Pacific," 22nd Conference on Hurricanes and Tropical Meteorology, Fort Collins, CO, 19-23 May 1997.

Elsberry, R.L., "Application of the Systematic Approach in the Eastern Pacific," Interdepartmental Hurricane Conference, Miami, FL, 25-28 March 1997.

**THESIS DIRECTED:**

Boothe, M.A., "Extension of the Systematic Approach to Tropical Cyclone Track Forecasting in the Eastern and Central Pacific," Master's Thesis, Naval Postgraduate School, December 1997.

**DoD KEY TECHNOLOGY AREA:** Battlespace Environments

**KEYWORDS:** Tropical Cyclone Motion, Tropical Cyclone Prediction

## MONSOON DISTURBANCES OVER THE CHINA SEAS

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**Sponsors: Office of Naval Research and Naval Postgraduate School**

**OBJECTIVE**: This research is to use operational Naval regional models to study the development of the southwest monsoon over the South China Sea and East China Sea, and its effects on weather disturbances over Southeast and East Asia.

**SUMMARY**: In 1996 the input interface of NORAPS was changed to allow both NOGAPS and ECMWF analyses and an objective analysis package for conducting data impact studies was installed. The first study using the model is to evaluate the prediction, relative to different initial data analyses, of a July 1991 Mei-Yu disturbance, which is one of the heaviest-rainfall events in East Asia and East China Sea. The result demonstrates the sensitivity of the model forecast with two different sets of initial data: the 1.125∞ ECMWF analysis with and without enhancement from a special Chinese radiosonde data set that was collected post-real time. In summary, the sensitivity and data impact experiments show that the difference between a high resolution global analysis such as the ECMWF and an analysis enhanced by a post-real time radiosonde data set can be significant in forecasting the intensity of the severe monsoon disturbance. A small initial error in pressure can cause a large 24-hour forecast error in rainfall, but the initial wind enhancement is much less consequential as it will adjust to the pressure field. While the main impact is at the lower level, the upper tropospheric data is also important. Apparently the tropopause process plays a significant role in the development and maintenance of the severe monsoon disturbance. These results will be presented to the First WMO International Workshop on Monsoons (Chang and Yi, 1997).

Another purpose of this project is to evaluate the Navy operational models relative to their application in the tropical monsoon area. When NORAPS was applied to the East Asia - South China Sea - West Pacific region a lateral boundary problem was found in the 24-48 hour geopotential height and mean sea level, where grid points near the lateral boundaries show isoplethes that are parallel to the boundary. The problem normally appears in the southern and western boundaries, and sometimes in the eastern boundary as well. The problem is summarized in a interim report (Yi and Chang, 1996) and tests are being carried out with the help of NRL-Monterey scientists. Systematic errors of NOGAPS and NORAPS from summer 1995 to winter1996 were analyzed when persistent weakening of the tropical upper tropospheric trough in the NOGAPS forecasts was observed. The error can be traced to a secondary circulation that is set up by a dry bias covering a broad northern tropical region extending from the western North Pacific to the South China Sea, Bay of Bengal, and the eastern Arabian Sea. In the meantime, wet bias appears in the southern equatorial region, particularly the Indian Ocean where strong 850 hPa cyclonic bias prevails. The results suggest that the tropical Western Pacific bias is probably not directly affected by the local sea surface temperature (SST) errors or the Indian Ocean systematic errors. On the other hand, NOGAPS shows a bias that tends to shift the precipitation maximum from the ITCZ and SPCZ to their poleward sides. The NORAPS errors in July 1995 can mostly be explained by boundary condition contamination from the NOGAPS errors. In January 1996 NOGAPS shows a similar pattern of systematic errors in the tropical Pacific and Indian Oceans although the magnitudes are smaller than July 1995. Significant remote influences of the Indian region errors can be detected in a Rossby-type teleconnection that propagates to the eastern North Pacific. It also exerts interesting influences on the NORAPS bias patterns over East Asia and western Pacific at 48-h forecast time. These results are reported in Chang et al., 1996.

**PUBLICATIONS**:

Chang, C.-P. and Yi, Lan, "Forecast of A Severe East Asian Monsoon Disturbance Using Navy's Operational Regional Model: A Sensitivity Study on Initial Data Analysis," *Proceedings of the First WMO International Workshop on Monsoon Studies*, World Meteorological Organization, Geneva, Switzerland, pp. 14-18, 1997.

Chu, P.C. and Chang, C.-P., "South China Sea Warm Pool in Boreal Spring," *Advances in Atmospheric Sciences*, 14, pp. 195-206, 1997.

Chu, P.C., Tseng, H.C., Chang, C.-P., and Chen, J.M., "South China Sea Warm Pool Detected in Spring from the Navy's Master Oceanographic Observational Data Set (MOODS)," *Journal of Geophysical Research*, 102 C7, pp. 15761-15771, 1997.

**CONFERENCE PRESENTATION**:

Chang, C.-P. and Yi, Lan, "Forecast of A Severe East Asian Monsoon Disturbance Using Navy's Operational Regional Model: A Sensitivity Study on Initial Data Analysis," First WMO International Workshop on Monsoon Studies, Denpasar, Indonesia, 24-28 February 1997.

**THESIS DIRECTED**:

Jimenez, G., "Diurnal Variation over the Tropical Monsoon Region During Summer 1991," Master's Thesis, Naval Postgraduate School, March 1997.

**DoD KEY TECHNOLOGY AREAS:** Other **(**Environmental Effects, Modeling and Simulation)

**KEYWORDS:** Tropical Meteorology, Monsoon, China Seas

## IMPACT OF NSCAT DATA ON TROPICAL REGIONAL PREDICTION

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**Department of Meteorology**
**Sponsor: National Aeronautics and Space Administration-Jet Propulsion Laboratory**

**OBJECTIVE**: To use the NSCAT surface wind data in the numerical prediction model over tropical oceans, including tropical cyclones track models, to study the possible impact of the NSCAT data in weather analysis and forecasting.

**SUMMARY**: Experiments on the track forecast of two tropical cyclones in the equatorial South China Sea, 14 December 1996-20 December 1996 and 21 December 1996-24 December 1996 were completed. Both cases include rather weak tropical cyclones. The 1000 hPa wind was re-analyzed by introducing the NSCAT wind data in the Navy's Global Operational Atmospheric Prediction System Model (NOGAPS) data as the initial condition. The 24-hour prediction results are practically the same with or without the NSCAT data. The reason for this is because the NOGAPS forecast contained some tropical cyclones structure through operational bogus. Thus, even though the initial surface condition is considerably modified, by 12 h forecast time the upper-level bogus structure has overridden the surface modification resulting in practically no change for latter time forecasts. In future experiments tropical cyclone structure in the NOGAPS data will be filtered. Other initial global data sets without tropical cyclone bogus will also be used.

**DoD KEY TECHNOLOGY AREA:** Other (Environmental Effects)

**KEYWORDS:** Tropical Meteorology, Satellite Data, NSCAT Data, Tropical Cyclones

## COASTAL AEROSOL AND MARINE ATMOSPHERIC BOUNDRY LAYER (MABL) PROPERTY INVESTIGATIONS WITH REMOTE AND IN SITU DATA COLLECTION

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**C. H. Wash, Professor**
**Department of Meteorology**
**Sponsor: Space and Naval Warfare Systems Center-San Diego**

**OBJECTIVE:** To provide capability to model of near-surface optical propagation and to obtain remote sensing derived estimates of coastal marine atmospheric boundary layer properties including coastal aerosol.

**SUMMARY:** In situ shipboard atmospheric boundary layer measurements were performed for coastal aerosol characterization studies from 10 to 21 March 1997 off the Central and Southern California coast. Buoys were deployed at midpoints of two transmission paths (7 and 15 km) from 25 August-5 September 1997. EOPACE 1996-97 transmission data and midpoint atmospheric refraction and turbulence data were collaboratively investigated for appropriateness of existing models relating bulk prediction to propagation phenomena. The combination of point (ship and/or near-shoreline) and satellite descriptions from EOPACE '96/97 campaigns were performed to evaluate remote sensing of horizontally transported coastal aerosol; primarily with the National Oceanic and Atmospheric Administration's polar orbiting satellite.

**PUBLICATIONS:**

De Jong, A.N., de Leeuw, G., and Davidson, K.L., "Low Elevation Transmission Measurements at EOPACE Part III: Scintillation Effects," *Proceedings of the SPIE Annual Meeting, Propagation and Imaging through the Atmosphere Conference,* Vol. 3125, San Diego, CA, 29-31 July 1997.

Jordan, M., Wash, C.H., and Cook, J., "Boundary Layer Variations Affecting Refraction During SHAREM 110," *Proceedings of CNMOC/DDR&E EMEO Tactical Symposium,* pp. 401-408, Naval Postgraduate School, Monterey, CA, 2-6 June 1997.

Kiser, R.E., Davidson, K.L., and Philbrick, C.R., "The Generation and Characterization of Surf Zone Aerosol and Their Impact on Naval Electro-Optical Systems," *Proceedings of CNMOC/DDR&E EMEO Tactical Symposium,* pp. 355-376, Naval Postgraduate School, Monterey, CA, 2-5 June 1997.

Veefkind, P., de Leeuw, G., Davidson, K.L., Jordan, M., Wash, C.H., Durkee, P.A., and Smith, M., "EOPACE Air Mass Characterization," *Proceedings of the SPIE Annual Meeting, Propagation and Imaging Through the Atmosphere Conference,* Vol. 3125, San Diego, CA, 29-31 July 1997.

Wash, C.H., Davidson, K.L., and Jordan, M.S., "Remote Sensing of Atmospheric Mixed-Layer, Depths in the Coastal Region," *Proceedings of the Progress in Electromagnetic Research Symposium (PIERS),* Hong Kong, 6-8 January 1997.

Zeisse, C.R., Gathman, S.G., de Jong, A.N., de Leeuw, G., Forand, J.L., Dion D., and Davidson, K.L., "Low Elevation Transmission Measurements at EOPACE Part I: Molecular and Aerosol Effects," *Proceedings of the SPIE Annual Meeting, Propagation and Imaging through the Atmosphere Conference,* Vol. 3125, San Diego, CA, 29-31 July 1997.

**CONFERENCE PRESENTATIONS:**

De Jong, A.N., de Leeuw, G., and Davidson, K.L., "Low Elevation Transmission Measurements at EOPACE Part III: Scintillation Effects," SPIE Annual Meeting, Propagation and Imaging through the Atmosphere, Conference, San Diego, CA, 29-31 July 1997.

De Jong, A.N., de Leeuw, G., and Davidson, K.L., "Low Elevation Transmission Measurements at EOPACE Part I: Molecular and Aerosol Effects," SPIE Annual Meeting, Propagation and Imaging through the Atmosphere Conference, San Diego, CA, 29-31 July 1997.

Wash, C.H., Davidson, K.L., and Jordan, M.S., "Multispectral Remote Sensing of the Coastal Atmospheric Boundary Layer," Progress in Electromagnetic Research Symposium (PIERS), Hong Kong, 6-9 January 1997.

Fourand, J.L., Dion, D., Duffy, M., de Jong, A., de Leeuw, G., Gathman, S., Littfin, K., Davidson, K.L., "Low-Level IR Transmission Measurements over a 15 km Littoral Path," 1997 Battlespace Atmospheric Conference, San Diego, CA, 2-4 December 1997.

Frederickson, P.A., Davidson, K.L., and Wash, C.H., "Buoy Measurements of Near-Horizon Optical Properties During EOPACE," 1997 Battlespace Atmospheric Conference, San Diego, CA, 2-4 December 1997.

Frederickson, P., Davidson, K.L., and de Jong, A., "Near-surface Scintillation ($Cn^2$) Estimated from a Buoy During EOPACE," NATO R&T Symposium: E-O Propagation, Signature and System Performance Under Adverse Meteorological Conditions Considering Out-of-Area Operations, Naples, Italy, 16-19 March 1998.

Veefkind, P., de Leeuw, G., Davidson, K.L., Jordan, M., Wash, C.H., Durkee, P.A., Smith, M.H., "EOPACE Air Mass Characterization," SPIE Annual Meeting, Propagation and Imaging through the Atmosphere Conference, San Diego, CA, 29-31 July 1997.

Wash, C.H., Jordan, M.S., Aie, P., Veefkind, P., and de Leeuw, G., "EOPACE Satellite and In Situ Optical Depth Studies," 1997 Battlespace Atmospheric Conference, San Diego, CA, 2-4 December 1997.

Wash, C.H., Jordan, M., and de Leeuw, G., "Satellite and Ship-Based LIDAR Measurements of Optical Depth during EOPACE," NATO R&T Symposium: E-O Propagation, Signature and System Performance Under Adverse Meteorological Conditions Considering Out-of-Area Operations, Naples, Italy, 16-19 March 1998.

Zeisse, C.R., Gathman, S.G., de Jong, A.N., de Leeuw, G., Forand, J.L., Dion, D., and Davidson, K.L., "Low Elevation Transmission Measurements at EOPACE Part I: Molecular and Aerosol Effects," SPIE Annual Meeting, Propagation and Imaging through the Atmosphere Conference, San Diego, CA, 29-31 July 1997.

Zeisse, C., Gathman, S., Barrios, A., Morrison, B., Davidson, K.L., and Frederickson, P., "Low Altitude Infrared Transmission," 1997 Battlespace Atmospheric Conference, San Diego, CA, 2-4 December 1997.

**THESES DIRECTED:**

Brown, B., "Remote Measurement of Aerosol Optical Properties Using the NOAA POES AVHRR and GOES IMAGER During TARFOX," Master's Thesis, Naval Postgraduate School, June 1997.

Kiser, R., "Coastal Internal Boundary Layer (IBL) Influence on Surface Zone Aerosol Properties," Master's Thesis, Naval Postgraduate School, March 1997.

Koch, C., "Operational Evaluation of the Electro-Optical Tactical Decision Aid, Version 3.1," Master's Thesis, Naval Postgraduate School, March 1997.

Yeoh, Lean-Weng, "Low Altitude Optical Signal Propagation over the Ocean," Doctor of Philosophy Dissertation, Naval Postgraduate School, March 1997.

**DoD KEY TECHNOLOGY AREAS**: Battlespace Environments, Sensors

**KEYWORDS:** Meteorological Measurement, Marine Atmosphere Boundary Layer, Optical Transmission, Optical Depth

## DEMONSTRATION/VALIDATION OF SURFACE COMBATANT IN SITU METOC SENSORS (SCIMS)

**K. L. Davidson, Professor**
**C. H Wash, Professor**
**Department of Meteorology**
**Sponsor: Space and Naval Warfare Systems Command**

**OBJECTIVE:** To provide capability to obtain descriptions of EM/EO conditions from surface combatants in the Littoral Zone on the basis of in situ measurements through the use of state-of-the-art commercial off-the-shelf METOC instrumentation.

**SUMMARY:** This is a continuing program in which METOC systems are being evaluated for use on operational ships. These were evaluated during buoy and shipboard deployments. Deployments and analyses were designed for evaluation of measurement accuracy, acquisition adaptability and field performances. A candidate system was selected for focusing further analyses and evaluations against other components. Evaluation of operational estimation of the evaporation duct regions through modeling and measurement were performed. Analyses and interpretation of the operational use of the Low-Altitude Rocket Dispensed Sonde (LARDS), i.e., Rocketsond and a LIDAR for shipboard profiles were performed.

**PUBLICATIONS:**

Baldauf, B., Davidson, K.L., and Wash, C.H., "Evaluation of Low Altitude Rocket Dropsondes for EM Propagation Assessment," *Proceedings of CNMOC/DDR&E EMEO Tactical Symposium*, pp. 421-430, Naval Postgraduate School, Monterey, CA, 2-6 June 1997.

Davidson, K.L., Wash, C.H., Goroch, A., and Pastore, M.J., "Development of the Surface Combatant In Situ Sensors (SMOOS(R)) Suite," *Proceedings of CNMOC/DDR&E EMEO Tactical Symposium*, pp. 97-102, Naval Postgraduate School, Monterey, CA, 2-6 June 1997.

Frederickson, P.A., Davidson, K.L., and Edson, J.B., "A Study of Wind Stress Determination Methods from a Ship and an Offshore Tower," *Journal of Atmospheric and Oceanic Technology*, 14, pp. 822-834, 1977.

Philbrick, C.R., Lysak, D.B., Jr., O'Brien, M., and Harrison, D.E., "LIDAR Measurements of Atmospheric Properties," *Proceedings of CNMOC/DDR&E EMEO Tactical Symposium*, pp. 385-400, Naval Postgraduate School, Monterey, CA, 2-5 June 1997.

**DoD KEY TECHNOLOGY AREAS**: Battlespace Environments, Sensors

**KEYWORDS:** Meteorological Measurement, Marine Atmosphere Boundary Layer, Radar Refraction

## DEMONSTRATION OF TDROP FOR USE IN JOINT TRI-SERVICE EXERCISE

**K. L. Davidson, Professor**
**Department of Meteorology**
**Sponsors: Naval Research Laboratory**

**OBJECTIVE:** To verify/validate TDrop as a Joint Tri-Service capability using coordinated TDrop airdrops, under parachute, and shipboard rawinsonde launches. Comparisons are of vector wind, temperature, and humidity at pressure levels during field tests over the water.

**SUMMARY:** Current combat sophisticated sensors and "smart" weapons are critically dependent on the environmental status in the battlespace. A new device has been developed to provide capability to sample the EM/EO environment in the battlespace—TDrop. TDrop is a miniaturized rawindsonde that has been designed to be used in aircraft chaff launchers.

Verification/validation tests were performed off the California coast from 16-19 March 1997. The at-sea tests included rawinsonde launches from a research vessel and parachute descending TDrops and Dropsondes, dropped from a CESSNA-121. Eleven TDrops were successfully deployed of which nine were interpreted for the resulting temperature, humidity, and pressure profiles. TDrop temperature and humidity profiles lacked the required accuracy and vertical resolution, five meters in comparison with ship-launched rawinsondes profile. GPS winds were received from seven of the eleven, but could not be evaluated because of uncertainties in the TDrop values.

**PUBLICATION:**

Frederickson, P., Davidson, K.L., Pastore, M.J., Daniels, J., Frederick, G., Smith, M., and Ayers, G.**,** "Evaluation of The Tactical Dropsonde (TDrop) in the Coastal Environment," *Proceedings of CNMOC/DDR&E EMEO Tactical Symposium*, pp. 409-420, Naval Postgraduate School, Monterey, CA, 2-5 June 1997.

**DoD KEY TECHNOLOGY AREA:** Sensors

**KEYWORDS:** Meteorological Measurement, Marine Atmosphere Boundary Layer, Radar Refraction

## PRECISION AIR DELIVERY (PAD) IPT PARTICIPATION

**K.L. Davidson, Professor**
**Department of Meteorology**
**Sponsor: Naval Research Laboratory**

**OBJECTIVES:** To represent the Naval Research Laboratory Tactical Ocean Weapons System (NRL-TOWS) at Precision Air Delivery (PAD) Integrated Process Team (IPT) meetings. Interact with Joint Group involved with selecting/ evaluating possible tasks within Precision Air Delivery basic research program.

**SUMMARY**: A basic research program has been initiated to investigate the key enabling technologies necessary to support precision delivery of a wide range of cargo directly to the warfighter. Specific technology challenges include the prediction/measurement of winds in the drop zone. Requirements have become critical relative to accurate descriptions of vector winds in complex terrain regions where existing analyses/forecasting is not valid. Known limitations of existing rawinsonde/dropsonde measurements could affect mission accomplishment. The NRL-TOWS Office has determined that systems they are directing development of may provide needed measurement capability for the PAD. NRL-TOWS requested NPS to attend meetings of the PAD IPT and to provide briefings on NRL-TOWS status with regard to TDrop and other relevant measurement programs. Such meeting attendance occurred at Wright Patterson Air Force Base on 1 November 1996. A meeting follow-up and report was provided to NRL Code 7406.

**DoD KEY TECHNOLOGY AREAS**: Battlespace Environments, Sensors

**KEYWORDS:** Atmospheric Measurement, Radiosonde, Precision Air Drop

## EM/EO ASSESSMENT/MODEL EVALUATION

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**A.W. Cooper, Professor**
**D. L. Walters, Associate Professor**
**Department of Physics**
**Rama Janaswamy, Associate Professor**
**Department of Electrical and Computer Engineering**
**Sponsor: Naval Postgraduate School-Institute for Joint Warfare Analysis**

**OBJECTIVE:** To perform assessments of atmospheric models and measurement requirements for EM/EO factors on system performance in Joint Operations.

**SUMMARY:** This is a collaborative effort by faculty in three departments whose link is expertise and acknowledged applied and basic research experience on issues of characterizing/modeling atmospheric effects on Electromagnetic and Electro-optical (EM/EO) propagation. The Navy and Air Force together have total DoD "weather" forecasting/analysis responsibility. This also applies to operational assessment on the influence of the atmosphere on weapons systems. A program called NAVAF was established to coordinate forecasting for strategic and tactical forces and to cooperate in product development. NPS had an opportunity to be even more involved with Joint EM/EO assessment activity because faculty initiated (in FY97) interaction with Commander Third Fleet (C3F). C3F is a joint fleet commander with Navy, Air Force, Army and Marine Corps on his staff and conducts Joint Operations. Accomplishments in CY97 include: (1) participating in organization of and being the host for the Joint EM/EO Prediction Requirements and Products Symposium held at NPS, 2-5 June 1997 and (2) performing of special analyses and surveys related to EM/EO models and their data requirements.

**PUBLICATIONS:**

Baldauf, B., Davidson, K.L., and Wash, C.H., "Evaluation of Low Altitude Rocket Dropsondes for EM Propagation Assessment," *Proceedings of the CNMOC/DDR&E EMEO Tactical Symposium*, pp. 187-198, Naval Postgraduate School, Monterey, CA, 2-6 June 1997.

Cooper, A.W., "Comparison of Issues in Infrared Imaging of Ships Against Background," *Proceedings of the CNMOC/DDR&E EMEO Tactical Symposium*, pp. 187-198, Naval Postgraduate School, Monterey, CA, 2-6 June 1997.

Davidson, K.L., Wash, C.H., Goroch, A., and Pastore, M.J., "Development of the Surface Combatant In Situ Sensors (SMOOS(R)) Suite," *Proceedings of the CNMOC/DDR&E EMEO Tactical Symposium*, pp. 97-103, Naval Postgraduate School, Monterey, CA, 2-6 June 1997.

Frederickson, P., Davidson, K.L., Pastore, M.J., Daniels, J., Frederick, G., Smith, M., and Ayers, G., "Evaluation of The Tactical Dropsonde (TDrop) in the Coastal Environment," *Proceedings of the CNMOC/DDR&E EMEO Tactical Symposium*, pp. 409-420, Naval Postgraduate School, Monterey, CA, 2-5 June 1997.

Goroch, A.K. and Koch, C., "Evaluation of the Electro-Optical Met Aid (EOMDA)," *Proceedings of the CNMOC/DDR&E EMEO Tactical Symposium*, pp. 25-32, Naval Postgraduate School, Monterey, CA, 2-5 June 1997.

Janaswamy, R., "A Curvilinear PE Approach to EM Propagation Predictions Over Terrain," *Proceedings of the CNMOC/DDR&E EMEO Tactical Symposium*, Naval Postgraduate School, Monterey, CA, 2-5 June 1997.

Jordan, M., Wash, C.H., and Cook, J., "Boundary Layer Variations Affecting Refraction during SHAREM 110," *Proceedings of the CNMOC/DDR&E EMEO Tactical Symposium*, pp. 401-408, Naval Postgraduate School, Monterey, CA, 2-6 June 1997.

Philbrick, R.C., Lysak, D.B., Jr., O'Brien, M., and Harrison, D.E., "LIDAR Measurements of Atmospheric Properties," pp. 385-400, *Proceedings of the CNMOC/DDR&E EMEO Tactical Symposium*, Naval Postgraduate School, Monterey, CA, 2-5 June 1997.

Walters, D.L., "Optical Turbulence Modeling and Measurements for DoD Programs," *Proceedings of the CNMOC/DDR&E EMEO Tactical Symposium*, pp. 199-204, Naval Postgraduate School, Monterey, CA, 2-5 June 1997.

**DoD KEY TECHNOLOGY AREAS**: Battlespace Environments, Sensors

**KEYWORDS:** Atmospheric Measurement, EM/EO Modeling

## STUDIES OF THE EFFECTS OF SHIP ACTIVITY ON CLOUD PROPERTIES

**Philip A. Durkee, Professor**
**Department of Meteorology**
**Sponsor: Office of Naval Research**

**OBJECTIVE:** This project is part of a multi-year effort to characterize the effects of ships on marine clouds. In particular, the goal is to understand the fundamental processes responsible for the formation and persistence of ship tracks - curvilinear, bright cloud features observed in near-infrared satellite imagery. The objectives during FY96 were threefold. First, analysis of the Monterey Area Ship Track (MAST) experiment was to be completed and the results of hypothesis tests were to be prepared for a special issue of the *Journal of Atmospheric Science (JAS)*. Second, analysis of worldwide ship track characteristics was continued along with investigation of the diversity of meteorological conditions under which ship tracks can form. Finally, analysis of the characteristics of ships that control formation of shiptracks was scheduled.

**SUMMARY:** The MAST Experiment was designed to test ten hypotheses on ship track formation, persistence, and required background conditions. The MAST Science Team was constructed in 1992-93 to provide the expertise to design and carry out the set of measurements required to test the hypotheses. The MAST was unique in that we were able to conduct a controlled experiment investigating a complex atmospheric phenomenon. The analysis of data and presentation of results was conducted as a team, incorporating multi-platform analysis of in situ measurements and model simulations. The formal publication of the *JAS* Special Issue represents a tightly focused presentation of results on a subject that has broad application of basic understanding of cloud microphysical and radiation processes to climatic impact of anthropogenic aerosol.

One year of data for three Pacific Ocean regional areas was analyzed and analyses of two other regions identified as potentially susceptible to ship track formation. In coordination with the analysis, the UK Ministry of Defense is processing data from three additional regions. This data set to date includes nearly 5000 ship tracks identified in NOAA AVHRR (Advanced Very High Resolution Radiometer) imagery at 3.7_m wavelength (AVHRR Channel 3

The testing of MAST hypotheses has identified aerosol directly injected from the stack of the ship as the primary source of cloud modification and formation of ship tracks. In addition, the more subtle roles of aerosol-cloud interaction on drizzle suppression and CCN enhancement by gas-to-particle conversion and cloud processes have been examined.

During MAST 5 U.S. Navy ships and 31 ships-of-opportunity were observed. In addition, satellite imagery was analyzed daily to study the large scale formation characteristics of ship tracks. Correlation of known ships to ship tracks yielded over 300 cases for analysis of the physical and radiative characteristics of ship tracks. In order to ensure high quality winds and ship information, 131 cases were analyzed to produce a composite picture of ship track properties. Analysis of 99 cases showed that, on average, ships are 16 km away from the head of the track as observed in AVHRR imagery. This distance corresponds to a mixing time of 25 minutes to transport the ship effluent to cloud top and disperse wide enough to brighten an AVHRR field-of-view.

Ship tracks occur in cloud-topped marine boundary layers. It is reasonable to expect that the depth of the boundary layer would affect the mixing processes and the concentration of aerosol produced by a ship. Analysis of soundings taken during MAST and SEAHUNT (Porch et al., 1995) showed a consistent reduction in ship track formation for boundary layers greater than 700m depth. This may be due to dilution of the aerosol concentration and may also be the result of internal stable layers that form more readily in deeper boundary layers and inhibit transport of the surface-based source of aerosol to the cloud.

The analysis of ship to ship track correlations also showed interesting effects of ship propulsion type and power on ship track formation. In general it was found that diesel ships that produce more aerosol than steam powered ships, produce brighter tracks that are wider and consistently more persistent. This is also true for ships of higher power output—consistent with production of more aerosols.

A worldwide set of AVHRR data has been collected for one year and is being processed. The regions of study include:

- Western North Pacific Ocean -100% complete
- Gulf of Alaska - 100% complete
- Eastern South Pacific Ocean - 100 % complete
- Eastern North Pacific Ocean - 100% complete
- Eastern South Atlantic Ocean - 100% complete
- Eastern North Atlantic Ocean - 100% complete (UK MOD)
- Barents Sea - in process (UK MOD)
- Indian Ocean - in process (UK MOD)

Preliminary results show ship track formation in a wide variety of locations and under diverse meteorological conditions. Although layer clouds with a transport mechanism to get ship effluent to the cloud is required, ship tracks have been observed at nearly all latitudes and seasons. Not all regions have been inspected equally but it is apparent that ship tracks are observed in many oceanic regions. Most stratus regions over eastern oceans exhibit tracks and ship track occurrence increases generally with increasing latitude coincident with increased stratus cloud cover.

A project has been started to investigate both automated detection of ship tracks and the provision of ship track information to ship surveillance agencies. Mission Research Corporation (MRC) has developed an automated scheme for track detection in AVHRR imagery based on an earlier technique developed at the Naval Postgraduate School. In addition to test and evaluation of these automated detection results, MRC is coordinating with the USCG to evaluate the utility of ship track information in the Joint Maritime Information Element (JMIE).

**DoD KEY TECHNOLOGY AREAS:** Sensors, Environmental Quality, Surface Vehicles – Ships and Watercraft

**KEYWORDS:** Marine Boundary Layer, Ship Effects, Cloud Physics, Aerosol Process, Aerosol/Cloud Interaction

## COASTAL AEROSOL CHARACTERIZATION

**Philip A. Durkee, Professor**
**Department of Meteorology**
**Sponsor: Office of Naval Research and Naval Postgraduate School**

**OBJECTIVE:** This project will combine model and observational studies to: (1) test the feasibility of integrating a full featured, process-oriented model with a meteorological model and (2) investigate initialization schemes for numerical models using data from remote sensing and point measurements. This is a joint project between NRL, Space and Naval Warfare Systems Center-San Diego, and NPS.

**SUMMARY:** To date the emphasis of this study has been on validation of aerosol optical depth retrievals from satellites with in situ measurements of the aerosol physical properties and integration of optical depth into model initialization schemes. In order for information about the horizontal aerosol distribution to be incorporated into a model, the information must be distributed in the vertical dimension. This requires assumptions since the satellite-retrieved value is a column integral of the aerosol properties. To first order the aerosol extinction is determined by concentration and relative humidity. A scheme has been developed as part of this project to distribute the aerosol extinction according to the vertical distribution of relative humidity. The scheme has been compared to aircraft and radiosonde measurements of relative humidity from several experiments including the Atlantic Stratocumulus Experiment (ASTEX), the Aerosol Characterization Experiment (ACE-1), Tropospheric Aerosol Radiative Forcing Observational Experiment (TARFOX), EOPACE and most recently ACE-2 (included two Desert Dust cases).

Information about the aerosol size distribution is also available from multispectral satellite measurements. The NPS optical depth retrieval uses this information to estimate the scattering phase function required for optical depth retrieval. The NPS approach has been compared to in situ data from field programs described above. The results have also been

compared with the NOVAM, a model of aerosol optical properties from parameterized size distributions. Early analysis indicates that the size information retrieved from satellite measurements can improve the NOVAM size distribution parameterization.

**DoD KEY TECHNOLOGY AREAS:** Sensors, Environmental Quality

**KEYWORDS:** Marine Boundary Layer, Aerosol Process, Aerosol/Cloud Interaction

### SYNOPTIC-BASED ANALOGUE TROPICAL CYCLONE TRACK PREDICTION TECHNIQUE FOR WESTERN NORTH PACIFIC

**Russell L. Elsberry, Professor**
**Jeng-Ming Chen, Research Assistant Professor**
**Department of Meteorology**
**Sponsor: Naval Research Laboratory**

**OBJECTIVE:** To demonstrate the feasibility of a tropical cyclone track prediction using an analogue technique based on the synoptic pattern/regions of the Systematic Approach.

**SUMMARY:** This is a new project begun in May 1997. A database of eight years (1989-1996) of western North Pacific tropical cyclones and associated synoptic pattern/region assigned has been prepared. An interactive version of the analogue technique has been coded.

**DoD KEY TECHNOLOGY AREA:** Battlespace Environments

**KEYWORDS:** Tropical Cyclones, Tropical Cyclone Track Prediction, Analogue Prediction Method

### SCIENTIFIC DATA IMPACT STUDY OF NASA SCATTEROMETER (NSCAT) OBSERVATIONS NEAR TROPICAL CYCLONES

**Russell L. Elsberry, Professor**
**Department of Meteorology**
**Sponsor: National Aeronautics and Space Administration-Jet Propulsion Laboratory**

**OBJECTIVE:** A data impact study of the NASA scatterometer (NSCAT) surface wind observations near tropical cyclones will be performed in conjunction with J. Goerss and J. Hawkins of the Naval Research Laboratory-Monterey.

**SUMMARY:** This is a new research project following the launch of the NSCAT instrument aboard the NASA-Japan ADEOS satellite on 16 August 1996. Unfortunately, the satellite failed in June 1997. All western North Pacific tropical cyclones while the satellite provided surface wind observations have been extracted. A Master's Thesis is in progress analyzing the surface winds. A separate effort at NRL-Monterey will assess the impact on tropical cyclone track predictions by the Navy Operational Global Atmospheric Prediction System (NOGAPS) of these NSCAT observations.

**DoD KEY TECHNOLOGY AREA:** Battlespace Environments

**KEYWORDS:** Tropical Cyclone Surface Winds, NASA Scatterometer Evaluation, Tropical Cyclone Track Prediction

## TROPICAL CYCLONE MOTION STUDIES

**Russell L. Elsberry, Professor**
**Lester E. Carr, III, Assistant Professor**
**Jeng-Ming Chen, Research Assistant Professor**
**Department of Meteorology**
**Sponsors: Office of Naval Research and Naval Postgraduate School**

**OBJECTIVE:** The long-term goal of this continuing project is to improve prediction of tropical cyclone track and structure so that warnings of Fleet units afloat and ashore are optimized. Short-term objectives are to develop objective aids tailored to specific synoptic pattern/region combinations of the Systematic Approach to provide better guidance and to improve the specification of the initial outer wind structure for numerical models, for forecaster understanding, and for use in surface wind warnings.

**SUMMARY:** Development of the Systematic Approach to Tropical Cyclone Track Forecasting has continued with a number of journal publications, conference presentations, and preprints. Statistical-synoptic equation sets for the Standard/ Dominant Ridge and Poleward/Poleward-Oriented pattern/region combinations have been demonstrated to have skill relative to climatology-persistence. Given a perfect knowledge of the type and timing of two transitions, the appending of a composited post-transition track led to about 50% reductions in 72-h track errors if the transition occurs early in the forecast interval. Based on the Joint Typhoon Warning Center specified wind radii during the intensification phase of western North Pacific tropical cyclones, 60% had continued growth, 24% contracted, and 16% maintained relatively constant in cyclone wind extent. During the decaying phase, 65% decreased, 29% had continued growth, and 6% had a relatively constant cyclonic wind extent. Reports of the ONR Tropical Cyclone Workshop in Melbourne, Australia (Abbey and Elsberry 1997) and a review of the Tropical Prediction Center/National Hurricane Center (Elsberry et al., 1997) were prepared, and a Hurricane Landfall Workshop was organized in November 1997 for the U.S. Weather Research Program.

**PUBLICATIONS:**

Abbey, R.F. and Elsberry, R.L., "Office of Naval Research Tropical Cyclone Workshop," 1997, in press.

Carr, L.E., III, Boothe, M.A., and Elsberry, R.L., "Observational Evidence for Alternate Modes of Track-Altering Binary Tropical Cyclone Scenarios," *Monthly Weather Review*, 125, pp. 2094-2111, September 1997.

Carr, L.E., III and Elsberry, R.L., "Models of Tropical Cyclone Wind Distribution and Beta-Effect Propagation for Application to Tropical Cyclone Track Forecasting," *Monthly Weather Review*, 125, pp. 3190-3209, December 1997.

Carr, L.E., III, Elsberry, R.L., and Boothe, M.A., "Systematic Approach to Tropical Cyclone Track Forecasting: Scenario-Specific Model and Objective Guidance Traits," *Preprints of the 22nd Conference on Hurricanes and Tropical Meteorology*, pp. 461-462, Fort Collins, CO, 19-23 May 1997.

Chen, J.-M., Elsberry, R.L., Boothe, M.A., and Carr, L.E., III, "A Simple Statistical-Synoptic Track Prediction Technique for Western North Pacific Tropical Cyclones," *Monthly Weather Review*, 1997, accepted.

Chen, J.-M., Boothe, M.A., Elsberry, R.L., and Carr, L.E., III, "Potential Systematic Approach Application: Synoptic-Based CLIPER for Western North Pacific," *Preprints of the 22nd Conference Hurricanes Tropical Meteorology*, pp. 463-464, Fort Collins, CO, May 1997.

Elsberry, R.L., Fisher, M., Carr, L.E., III, and Boothe, M.A., "Three Methods for Estimating the Outer Wind Structure of Western North Pacific Tropical Cyclones," *Preprints of the 22nd Conference Hurricanes Tropical Meteorology*, pp. 647-648, Fort Collins, CO, May 1997.

Elsberry, R.L., Baker, J., Holland, G., Knable, C., and Wash, C.H., "UCAR Review Panel Report on the Tropical Prediction Center/National Hurricane Center," University Corporation Atmospheric Research, Boulder, CO, June 1997.

Elsberry, R.L., Harr, P.A., Ritchie, E.A., Emanuel, K.A., Gordon, R.T., and Schoenung, S.M., "ERAST Tropical Cyclone Science Mission Demonstration Plan," Report prepared for NASA Environmental Research Aircraft and Sensor Technology (ERAST), 43 pp.

**CONFERENCE PRESENTATIONS:**

Carr, L.E., III, Elsberry, R.L., and Boothe, M.A., "Development of a Systematic and Integrated Approach to Tropical Cyclone Track Forecasting," Interdepartmental Hurricane Conference, Miami, FL, 25-28 March 1997.

Carr, L.E., III, Elsberry, R.L., and Boothe, M.A., "Progress Report on the Systematic Approach to Tropical Cyclone Track Forecasting," USPACOM Tropical Cyclone Conference, Tokyo, Japan, 25-28 February 1997.

Elsberry, R.L., Chen, J.-M., Boothe, M.A., and Carr, L.E., III, "A Synoptic-Based CLIPER for Western North Pacific Tropical Cyclones," USPACOM Tropical Cyclone Conference, Tokyo, Japan, 25-28 February 1997.

Elsberry, R.L., Fisher, M.R., Carr, L.E., III, and Boothe, M.A., "Outer Wind Structures of Western North Pacific Tropical Cyclones," USPACOM Tropical Cyclone Conference, Tokyo, Japan, 25-28 February 1997.

**DoD KEY TECHNOLOGY AREA:** Battlespace Environments

**KEYWORDS:** Tropical Cyclones, Tropical Cyclone Track Prediction, Tropical Cyclone Structure

## ATMOSPHERIC FORCING OF OCEAN CONVECTION IN THE LABRADOR SEA

**P. S. Guest, Meteorologist**
**Department of Meteorology**
**Sponsor: Office of Naval Research**

**OBJECTIVE:** The long-term goal of this research is to understand the relation between atmospheric forcing and ocean deep convection.

**SUMMARY:** During a 1997 winter cruise of the R/V *Knorr*, 217 rawinsonde (weather balloon) soundings of the atmosphere were successfully performed. These represent the only rawinsonde measurements ever performed in the central part of Labrador Sea. This information is crucial to understanding how the atmosphere forces the ocean. A successful radiation measurement program was also completed. Measurements of standard meteorological parameters (winds, temperature, humidity, pressure, and precipitation) as well as turbulent wind and temperature parameters were taken. Because the direct turbulence measurements are not yet processed to determine surface fluxes, the turbulent fluxes using a bulk method were estimated. Net radiation was determined from the direct measurements of downwelling radiation and estimates of upwelling radiation based on surface conditions (i.e., surface temperature and albedo). These measured and derived quantities represented all the terms in the surface heat and momentum fluxes. These measurement results were used to investigate the response of the ocean to atmospheric fluxes using an ocean mixed layer model.

**PUBLICATIONS:**

Pickart, R.S., Guest, P., Dobson, F., Anderson, R., Bumke, K., Uhlig, K., Karger, U., and Berndt, H., "*Knorr* 147 Leg V Cruise Summary: Labrador Sea Convection Experiment," 99 pp., Woods Hole Oceanographic Institution, Woods Hole, MA, 1997.

Rasmussen, E.A., Guest, P.S., and Davidson, K.L., "Synoptic and Mesoscale Features over the Ice-Covered Portion of the Fram Strait in Spring, *Journal of Geophysical Research*, 102, pp. 13,975-13,986, 1997.

**CONFERENCE PRESENTATIONS:**

Bramson, L., Guest, P., and Garwood, R., "The Effect of Atmospheric Forcing on the Labrador Sea on the Mixed Layer in the Winter of 1997," American Geophysical Union 1998 Ocean Sciences Meeting, San Diego, CA, 13 February 1998.

Guest, P.S., "Marginal Ice Zone Meteorology," IAMAS/IAPSO Joint Assembly, Melbourne, Australia, 2 July 1997.

Guest, P., "Atmospheric Forcing Conditions in the Labrador Sea: Results from the 1997 R/V *Knorr* Cruise," American Geophysical Union 1998 Ocean Sciences Meeting, San Diego CA, 13 February 1998.

**THESIS DIRECTED:**

Bramson, L., "Air-Sea Interactions and Deep Convection in the Labrador Sea," Master's Thesis, Naval Postgraduate School, December 1997.

**DoD KEY TECHNOLOGY AREAS:** Other (Meteorology, Physical Oceanography)

**KEYWORDS**: Convection, Polar Meteorology, Air-Sea Interactions

## MEASURING, PARAMETERIZING, AND MODELING ATMOSPHERIC SURFACE FLUXES DURING SURFACE HEAT BUDGET OF THE ARCTIC OCEAN (SHEBA)

**P. S. Guest, Meteorologist**
**Department of Meteorology**
**Sponsor: National Science Foundation**

**OBJECTIVES:** (1) to provide direct estimates of the surface energy, momentum, and mass budgets over different surface types (i.e., new ice, first-year ice, multiyear ice, deformed ice, open water, melt ponds, etc.) and area averages of these for the SHEBA region for the duration of the experiment; (2) to investigate parameterizations of the turbulent transfer coefficients and modifications to Monin-Obukhov similarity theory necessary in a stably stratified atmospheric surface layer; and (3) to obtain high quality radiative flux and albedo data at multiple locations for investigating ice-albedo and cloud-albedo feedback.

**SUMMARY:** The program to study the Surface Heat Budget of the Arctic Ocean (SHEBA) is a multidisciplinary undertaking centered around a 13-month experiment at a camp placed on drifting ice in the Beaufort Sea. This is the first year of a three-year program. The focal point of the research is a 20-m tower at the main SHEBA camp. This has multiple levels of instruments for measuring mean wind speed, direction, temperature, and humidity and three levels with fast-responding instruments for measuring turbulent fluxes directly by eddy correlation. Near this tower are a variety of instruments for measuring radiative fluxes and surface temperature. Similar instruments, but at one level only, are deployed at four sites 3-5 km from the main camp. The measurements phase is still in progress and no publications or presentations have been produced yet.

**DoD KEY TECHNOLOGY AREAS:** Other (Meteorology, Physical Oceanography)

**KEYWORDS**: Polar Meteorology, Air-Sea-Ice Interactions, Surface Fluxes

### ATMOSPHERIC FORCING DURING THE ANZONE WINTER FLUX EXPERIMENT (ANZFLUX)

**P.S. Guest, Meteorologist**
**K. L. Davidson, Professor**
**Department of Meteorology**
**Sponsor: National Science Foundation**

**OBJECTIVE**: The research was a closely integrated part of a multiple investigator program called the Antarctic Zone Flux Experiment (ANZFLUX) which addressed the problem of explaining the anomalously high heat fluxes which occur across the oceanic mixed layer in the Eastern Weddell Sea. Atmospheric forcing of the upper ocean was measured and analyzed using instruments from ship, ice floe, and balloon platforms.

**SUMMARY:** April 1997 was the final month of funding for this three-year program to characterize air-sea-ice interactions in the Weddell Sea. It was found that the variations and the mean value of the total surface heat flux were primarily determined by the longwave radiation balance during the ANZFLUX project. The longwave radiation balance, in turn, was mostly controlled by the amount of clouds. Despite intense storm activity, cloud conditions, not surface wind speed nor air temperature, dominated the direct thermodynamic forcing of the atmosphere on the ocean.

**PUBLICATION:**

Guest, P., "Surface Radiation Conditions in the Eastern Weddell Sea During Winter," *Journal of Geophysical Research*, 1997, submitted.

**CONFERENCE PRESENTATION:**

Guest, P., "The Surface Heat Budget of the Eastern Weddell Sea in Winter with Emphasis on Longwave Radiational Processes," International Antarctic Zone 5th Coordination Meeting, Biosphere-2, Oracle, AZ, 1-5 December 1997.

**THESIS DIRECTED:**

Tramm, E., "A Study of the Surface Heat Budget of the Weddell Sea Using a Radiative Transfer Model During the Austral Winter 1994," Master's Thesis, Naval Postgraduate School, March 1997.

**DoD KEY TECHNOLOGY AREAS:** Other (Meteorology, Physical Oceanography)

**KEYWORDS**: Polar Meteorology, Air-Sea-Ice Interactions, Surface Radiation

### DATA ASSIMILATION AND MODEL SIMULATIONS IN THE CALIFORNIA CURRENT

**Robert L. Haney, Professor**
**Department of Meteorology**
**Sponsor: Office of Naval Research**

**OBJECTIVE:** The broad objective of this research is to aid in the development of a reliable modeling capability for eastern boundary current regions. The specific objective is to carry out and extensively verify several DieCAST model simulations of the annual cycle in the California Current. The wish is to also develop and apply digital filter initialization (DFI) as a diagnostic tool in numerical ocean prediction.

**SUMMARY:** The DieCAST A-grid, low-dispersion (nearly 4th order) regional model (Dietrich 1997) was adapted to the California coastal domain with lateral boundary conditions prescribed using data from both an observed monthly climatology and a global numerical model. Two six-year long numerical simulations were completed. One of the simulations uses a climatological annual cycle of wind stress forcing, while the other simulation includes an additional wind stress enhance-

ment near each coastal headland that is representative of that observed (e.g., Enriquez and Friehe 1995). Using climatological wind forcing, the DieCAST model reproduces many of the main features of the observed annual cycle of the California Current including the separation of the coastal jet from the coast in late summer and its offshore migration in autumn and winter. Coastal eddies in the simulation form primarily off the major headlands, especially Cape Mendocino and Point Arena. The surface eddy kinetic energy is in the range of that observed and it undergoes a seasonal cycle with a phase that varies with distance from shore similar to that observed. The additional forcing by the headland wind jets is found to produce both local and remote changes to the simulated annual cycle.

**PUBLICATIONS:**

Dietrich, D., Haney, R.L., Mehra, A., and Piacsek, S., "Comments on 'A Method for Improved Representation of Dense Water Spreading over Topography in Geopotential Coordinate Models,'" *Journal of Physical Oceanography*, 1998, submitted.

Chumbinho, R., Haney, R.L., and Ramp, S., "Kinematics and Dynamics of a Cyclonic Eddy off of Point Arena, California," *Journal of Physical Oceanography*, 1998, in revision.

Viudez, A. and Haney, R.L., "On the Relative Vorticity of the Atlantic Jet in the Alboran Sea," *Journal of Physical Oceanography*, 27, pp. 175-185, 1997.

Viudez, A. and Haney, R.L., "The Deflection and Division of an Oceanic Baroclinic Jet by a Coastal Boundary: A Case Study in the Alboran Sea," *Journal of Physical Oceanography*, 28, 1998, in press.

Viudez, A., Pinot, M., and Haney, R.L., "On the Upper Layer Circulation in the Alboran Sea," *Journal of Geophysical Research*, 1998, submitted.

**CONFERENCE PRESENTATION:**

Haney, R.L., Dietrich, D.E., and Hale, R.A., "The Role of Headland Wind Jets in the Annual Cycle of the California Current System," 44th Eastern Pacific Ocean Conference (EPOC), Fallen Leaf Lake, CA, 16-19 September 1997.

**DoD KEY TECHNOLOGY AREA:** Other **(**Environmental Effects)

**KEYWORDS:** Coastal Physical Oceanography, Numerical Ocean Modeling

## TROPICAL CYCLONE MOTION STUDIES

**Patrick A. Harr, Research Assistant Professor**
**Russell L. Elsberry, Professor**
**Department of Meteorology**
**Sponsor: Office of Naval Research**

**OBJECTIVE:** Observations suggest that the outer wind structure of the mature tropical cyclone, which is important to understanding its motion over short time scales, is dependent on growth, evolution, and decay characteristics of mesoscale convective systems (MCSs) and associated midlevel vortices. The objective of this portion of the continuing project is to improve understanding of factors that control MCS evolution in the tropical cyclone environment and the relationships between the MCS development and the large-scale environment.

**SUMMARY:** High-resolution satellite imagery was used in conjunction with numerical analyses from the Navy Operational Global Atmospheric Prediction System (NOGAPS) to examine the interaction between MCS evolution, tropical cyclone characteristics, and the large-scale environment. The relative importance of MCS activity to tropical cyclone development and eventual mature structure was described by a conceptual model. The model was examined through objec-

tive determination of MCS activity for a variety of tropical cyclone evolutions. Results suggested that MCS size and duration could be related to each type of tropical cyclone development as defined in the conceptual model. Furthermore, the study defined the means by which MCS evolution associated with tropical cyclone activity could be examined with respect to general MCS activity throughout the tropical western North Pacific environment.

**PUBLICATION:**

Harr, P.A., Finta, C.A., and Elsberry, R.L., "Role of Mesoscale Convective Vortices in Determining the Circulation Structure During Tropical Cyclone Formation," *Preprints, Twenty-Second Conference on Hurricanes and Tropical Meteorology,* pp. 194-195, Fort Collins, CO, 19-23 May 1997.

**CONFERENCE PRESENTATIONS:**

Harr, P.A., "Tropical Cyclone Structure in Relation to Mesoscale Convective Systems," USPACCOM Tropical Cyclone Conference, Tokyo, Japan, 25-28 February 1997.

Harr, P.A., "Use of Unmanned Aerial Vehicles (UAVs) for Landfalling Tropical Cyclone Prediction and Tropical Cyclone Formation Studies," NASA Environmental Research Aircraft and Sensor Technology (ERAST) Meeting of the Hurricane Task Force, Vienna, VA, 4 May 1997.

**THESIS DIRECTED:**

Finta, C.A., "Observations of Mesoscale Convective Systems During Tropical Cyclone Genesis," Master's Thesis, Naval Postgraduate School, March 1997.

**DoD KEY TECHNOLOGY AREAS:** Environmental Quality, Modeling and Simulation, Other (Environmental Effects)

**KEYWORDS:** Tropical Cyclones, Mesoscale Convective Systems

## IMPACTS OF THE EXTRATROPICAL TRANSITION OF TROPICAL CYCLONES ON PREDICTIONS OF MIDLATITUDE CIRCULATION SYSTEMS BY THE NAVY OPERATIONAL GLOBAL ATMOSPHERIC PREDICTION SYSTEM

**Patrick A. Harr, Research Assistant Professor**
**Russell L. Elsberry, Professor**
**Department of Meteorology**
**Sponsor: Naval Research Laboratory**

**OBJECTIVE:** The primary objective is to identify physical processes that are associated with the extratropical transition of tropical cyclones that have direct impact on the redevelopment as a midlatitude cyclone and on predictions of that redevelopment.

**SUMMARY:** A review of cases of extratropical transition of tropical cyclones over the western North Pacific from July-October 1990-1996 was conducted. A definition of the variability of the midlatitude circulation that the tropical cyclone was moving into during transition was used to identify several synoptic models that could be applied at the time of transition to assess the potential impact on the downstream midlatitude circulation systems. Furthermore, specific physical attributes associated with the transition were examined to assess their relative roles in determining the type of midlatitude redevelopment that occurred and was forecast to occur. Results indicate that during transition the atmosphere is particularly sensitive to processes that release a concentrated amount of energy in an environment that is dynamically favorable for extratropical cyclogenesis. The phasing of the tropical cyclone with the midlatitude circulation into which it is moving determines the degree of sensitivity and the amount of extratropical redevelopment that occurred.

**PUBLICATION:**

Klein, P.M., Harr, P.A., and Elsberry, R.L., "Extratropical Transition of Western North Pacific Tropical Cyclones," *Preprints, Twenty-Second Conference on Hurricanes and Tropical Meteorology*, pp. 364-365, Fort Collins, CO, 19-23 May 1997.

**CONFERENCE PRESENTATIONS:**

Harr, P.A., "Impacts of Extratropical Transition of Tropical Cyclones," USPACCOM Tropical Cyclone Conference, Tokyo, Japan, 25-28 February 1997.

Harr, P.A., "Extratropical Transition," Workshop on Tropical Cyclone and Trough Interactions, Bad Tolz, Germany, 4-8 August 1997.

**THESIS DIRECTED:**

Klein, P.M., "Extratropical Transition of Western North Pacific Tropical Cyclones," Master's Thesis, Naval Postgraduate School, September 1997.

**DoD TECHNOLOGY AREAS:** Environmental Quality, Modeling and Simulation, Other (Environmental Effects)

**KEYWORDS:** Tropical Cyclones, Extratropical Transition, Midlatitude Cyclones, Numerical Weather Prediction.

## MULTI-SCALE AIR-SEA INTERACTIONS

**Tianming Li, Research Assistant Professor**
**C.-P. Chang, Professor**
**Department of Meteorology**
**Sponsor: Naval Research Laboratory**

**OBJECTIVE**: To investigate multi-scale air-sea interactions in a coupled system and understand the physical mechanisms that determine the El Niño and the Southern Oscillation.

**SUMMARY**: The physical mechanisms that determine the north-south climatic asymmetry of the Intertropical Convergence Zone and determine the El Niño-Southern Oscillation phenomenon were investigated by means of simple conceptual coupled air-sea models and complex coupled general circulation models. A new ENSO theory was proposed based on observational analyses. The role of the time averaged of tropical climate on several observational analyses. The role of the time averaged state of tropical climate on seasonal and interannual variability was examined. The relative roles of clouds, surface evaporation, and ocean heat transport in the regulation of maximum sea surface temperatures in the tropics were also studied.

**PUBLICATIONS:**

Li, T., "Air-Sea Interactions of Relevance to the ITCZ: Analysis of Coupled Instabilities and Experiments in a Hybrid Coupled GCM," *Journal of the Atmospheric Sciences*, Vol. 54, No. 1, pp. 134-147, 1997.

Li, T., "Phase Transition of the El Niño-Southern Oscillation: A Stationary SST Mode," *Journal of the Atmospheric Sciences*, Vol. 54, No. 24, pp. 2872-2887, 1997.

**CONFERENCE PRESENTATIONS:**

Li, T. and Hogan, T.F., "Seasonal and Interannual Climate Variability in a Coupled GCM," IAMAP & IAPSO Conference, Melbourne, Australia, July 1997.

Li, T. and Hogan, T.F., "The Role of the Time Mean State on Seasonal and Interannual Variability in a Coupled GCM," 22nd Annual Climate Diagnostic and Prediction Workshop, Berkeley, CA, October 1997.

Li, T., Hogan, T.F., and Chang, C.-P., "Dynamic and Thermodynamic Regulation of Ocean Warming," American Geophysical Union Fall Meeting, San Francisco, CA, December 1997.

**DoD KEY TECHNOLOGY AREA:** Other (Environmental Effects)

**KEYWORDS**: Tropical Meteorology, Satellite Data, NSCAT Data, Tropical Cyclones

## DECADAL TELECONNECTIONS IN THE NORTH PACIFIC

**Tom Murphree, Research Assistant Professor**
**Department of Meteorology**
**Sponsor: National Oceanic and Atmospheric Administration**

**OBJECTIVES:** This is a new project designed to analyze the interactions of the ocean and atmosphere in the Northeast Pacific with remote parts of the global climate system occurring on decadal scales.

**SUMMARY:** This project is being conducted in collaboration with researchers at the Pacific Fisheries Environmental Laboratory (PFEL) of the National Oceanic and Atmospheric Administration. The goal is to develop a better understanding of the decadal variations of the Northeast Pacific Ocean, their interactions with the overlying atmosphere, and their teleconnections with remote parts of the ocean-atmosphere-land system. The project is part of a larger project titled, "Patterns, Sources, and Mechanisms of Decadal Environmental Variability in the Northeast Pacific: A Retrospective and Modeling Analysis," also being conducted by Professor Murphree and his collaborators at PFEL. This larger project examines decadal changes in the northeast Pacific and their role in ecosystem changes. Both projects are part of the northeast Pacific component of the Global Ocean Ecosystems Dynamics (GLOBEC) program. The primary research methods for both projects are: (1) analyses of observed oceanic and atmospheric data and (2) ocean model experiments.

The initial work on this project has focused on an analysis of the anomalies in several oceanic and atmospheric fields (e.g., sea surface temperature (SST), subsurface temperatures, sea level, surface and upper tropospheric winds) in the tropical and extratropical North Pacific during 1995-1997. The emphasis was on the evolution of seasonal to interannual anomalies during 1997. In the tropics, the major anomalies were part of the 1997-1998 El Niño event. In the extratropics, the initial anomalies were part of a longer term, and possibly decadal, event with links to the 1995-1996 La Niña event. During the early stages of the El Niño event (February-October 1997), there was little evidence of a direct link between the developing positive SSTAs in the equatorial central and eastern Pacific and the strengthening positive SSTAs in the extratropical northeast Pacific.

Instead, these northeast Pacific anomalies appear to have been driven by: (1) anomalous regional scale ocean-atmosphere feedbacks involving a weak development of the northeast Pacific (sea level pressure) High and (2) an anomalous atmospheric wave train emanating from East Asia during the summer and fall. The wave train appears to have been created by anomalous atmospheric convection and heating in the southeast Asian and Philippine Sea region. Both the regional feedbacks and the wave train contributed to an unusually weak northeast Pacific High during spring-fall 1997. This weak High led to weak southwestward trade winds, and contributed to the development of the El Niño event. Since the weak atmospheric heating and weak trades are part of the El Niño event, it appears that there may have been a feedback process operating during much of 1997 in which the tropical and extratropical Pacific anomalies reinforced each other. The evidence of a teleconnection involving oceanic Kelvin waves propagating from the equatorial Pacific into the extratropical northeast Pacific is very limited. However, there is evidence that poleward winds along the California coast may have generated coastal Kelvin waves during late winter and spring.

**PUBLICATIONS:**

Murphree, T., van den Dool, H., and Schwing, F., "The Early Impacts of the 1997-1998 El Niño Event on North America," to be submitted to *Science*, March 1998.

Murphree, T. and Schwing, F., "The Role of Extratropical North Pacific Processes in the Development of the 1997-1998 El Niño Event," to be submitted to *Science*, March 1998.

Schwing, F., Hayward, T., Sakuma, K., Murphree, T., Mascarenas, A., Castillo, S., Mantyla, A., Cummings, S., Chavez, F., Baltz, K., and Ainley, D., "The State of the California Current, 1996-1997: Mixed Signals From the Tropics," *California Cooperative Oceanic Fisheries Investigations Reports*, Vol. 38, 28-54, 1997.

**CONFERENCE PRESENTATIONS:**

Murphree, T. and Schwing, F., "Tropical-Extratropical Interactions in the North Pacific During the 1997-1998 El Niño Event," to be presented at the Ocean Sciences Meeting, American Geophysical Union, San Diego, CA, February 1998.

Murphree, T. and Schwing, F., "Climate Variations and the Monterey Bay Region," Annual Lecture Series of the Monterey Dunes Natural History Association, Monterey, CA, November 1997.

Murphree, T., van den Dool, H., and Schwing, F., "The Impacts of the 1997-1998 El Niño Event on the North Pacific and North America," to be presented at the Pacific Climate Workshop, Santa Catalina, CA, April 1998.

**DoD KEY TECHNOLOGY AREAS**: Other (Environmental Effects, Environmental Processes, Environmental Monitoring, Environmental Modeling)

**KEYWORDS**: Climate System, Decadal Variations, El Niño, GLOBEC, Kelvin Waves, La Niña, Northeast Pacific, Teleconnections, Wave Train

## PHYSICAL ASPECTS OF BIOLOGICAL VARIABILITY IN THE NORTHEAST PACIFIC OCEAN

**Tom Murphree, Research Assistant Professor**
**Department of Meteorology**
**Sponsor: National Oceanic and Atmospheric Administration**

**OBJECTIVES:** This is a new project designed to identify and develop indices based on oceanic and atmospheric factors that can be used to explain, and possibly predict, variations in salmon populations in the Northeast Pacific.

**SUMMARY:** This project is a collaborative effort with scientists at the Pacific Fisheries Environmental Laboratory of the National Oceanic and Atmospheric Administration. The project goal is to produce biologically relevant indices that represent important physical factors and processes, and their relationships with existing records of physical and biological change in the coastal areas of western North America. The focus is on local and remote oceanic and atmospheric processes affecting salmon in the Oregon-Washington region, and related changes in the Gulf of Alaska. Initial work has begun on identifying the interannual to decadal variations in the transport of energy, mass, and momentum into the northeast Pacific by the North Pacific Current (NPC), and the subsequent redistribution of NPC waters by the Alaska Current (AK) and California Current (CC). Early results support one of the project's hypotheses, that the long-term changes in the AC and the CC are out of phase with each other. This suggest that indices based on NPC variations may be especially useful for explaining and anticipating variations in the coastal northeast Pacific, a critical region for the success of many salmon populations.

**CONFERENCE PRESENTATIONS:**

Bollens, S., Collins, C., Dugdale, B., Wilkerson, F., Cordell, J., Cole, B., Cloern, J., Murphree, T., Rago, T., Hayden, T., Avent, S., and Franklin, H., "Effects of Massive Flooding on the Biology and Physics of the San Francisco Bay and the Gulf of the Farallones," 14th International Estuarine Research Federation Conference, Estuarine Research Federation, Boston, MA, September 1997.

Murphree, T. and Schwing, F., "Climate Variations," to be presented at the Gentrain Lecture Series, Monterey Peninsula College, Monterey, CA, January 1998.

**DoD KEY TECHNOLOGY AREAS**: Other (Environmental Effects, Environmental Processes, Environmental Monitoring, Environmental Modeling)

**KEYWORDS**: Biological Variability, Decadal and Interannual Variations, Oceanic and Atmospheric Indices, Salmon Populations

## TROPICAL AND GLOBAL PROCESSES

**Tom Murphree, Research Assistant Professor**
**Department of Meteorology**
**Sponsor: Naval Research Laboratory**

**OBJECTIVES:** This is a continuing project designed to determine the extent to which, and the mechanisms by which, tropical cyclones influence the circulation of distant parts of the extratropical atmosphere.

**SUMMARY:** This is a collaborative project with scientists at the Naval Research Laboratory in Monterey, CA. The focus is on how spatial and temporal variations in the ambient circulation affect the wave trains and teleconnections initiated by tropical cyclones (TCs). The results from modeling studies using the Navy's Operational Global Forecast Model (NOGAPS) and a nonlinear global shallow water model with realistic ambient fields were compared. Additional runs of the second model were used to clarify the low frequency wave dynamics associated with a variety of TC tracks in the Indian, Pacific, and Atlantic basins. The results from both models indicate that: (1) a recurving track is most effective at producing an extratropical wave train response to a TC; (2) wave train generation is most pronounced in regions of high ambient vorticity flux; (3) wave propagation is strongly guided by the subtropical jets; and (4) summer wave trains tend to be more zonal and less stationary than winter ones.

**PUBLICATIONS:**

Murphree, T. and Gelaro, R., "Equatorial Ocean Kelvin Waves and Tropical Cyclones during El Niño Events," *Journal of Geophysical Research*, May 1998 to be submitted.

Murphree, T. and Gelaro, R., "The Global Impacts of Tropical Cyclones. Part I: Idealized Model Results," *Journal of Climate*, April 1998 to be submitted.

Murphree, T., Gelaro, R., and Goerss, J., "The Global Impacts of Tropical Cyclones. Part II: Forecast Model Results," *Journal of Climate*, April 1998 to be submitted.

**PRESENTATIONS:**

Murphree, T., "El Niño Events and Their Global Impacts," Superintendent's Guest Lecture, Naval Postgraduate School, Monterey, CA, November 1997.

Murphree, T., "El Niño Events and Their Impacts on California," Meeting of California Governor's Staff Members with Monterey Bay Regional Consortium, Monterey, CA, November 1997.

**DoD KEY TECHNOLOGY AREAS:** Other **(**Environmental Effects, Environmental Processes, Environmental Monitoring, Environmental Modeling)

**KEYWORDS:** Climate Dynamics, Extended Range Forecasts, Teleconnections, Tropical Cyclones

## MAURY PROJECT DEVELOPMENT AND IMPLEMENTATION

**Tom Murphree, Research Assistant Professor**
**Department of Meteorology**
**Sponsor: U.S. Naval Academy**

**OBJECTIVES:** The is a new project designed to develop and present educational materials on physical oceanography to pre-college teachers.

**SUMMARY:** This project is conducted in collaboration with colleagues in the Oceanography Department of the U.S. Naval Academy and the American Meteorological Society (AMS). The project is part of a larger national Maury Project administered by the AMS, and funded by the National Science Foundation, the Naval Meteorology and Oceanography Command, and National Oceanic and Atmospheric Administration. The purpose of the national project is to develop and present educational materials on physical oceanography to pre-college teachers from around the country and other nations.

Several educational publications were produced and a two-week intensive summer course was presented. The oceanographic subjects covered by Professor Murphree in his work on the overall Maury Project included: currents, waves, tides, Ekman processes, air-sea interaction, ocean acoustics, El Niño and La Niña events, satellite sensing of the ocean, and ocean modeling. The summer presentations included at-sea, laboratory, and classroom presentations, including computer-aided analyses of oceanographic data. As part of the Naval Postgraduate School project, additional workshops were made to pre-college educators in California.

**PUBLICATIONS:**

Maury Project Team, "Air-Sea Interaction: A Maury Project Teacher's Guide," American Meteorological Society, 14 pp., Washington, D.C., 1997.

Maury Project Team, "Ocean Sound: A Maury Project Teacher's Guide," American Meteorological Society, 13 pp., Washington, D.C., 1997.

Maury Project Team, "Ocean Tides on the Web: A Maury Project Activity," American Meteorological Society, 8 pp., Washington, D.C., 1997.

Maury Project Team, "Shallow Water Ocean Waves: A Maury Project Teacher's Guide," American Meteorological Society, 15 pp., Washington, D. C., 1997.

Maury Project Team, "El Niño: A Maury Project Teacher's Guide," American Meteorological Society, Washington, D. C., 1998, in press.

Maury Project Team, "Ocean Eddies and Rings: A Maury Project Teacher's Guide," American Meteorological Society, Washington, D.C., 1998, in press.

Smith, D., Guth, P., Viera, M., Whitford, D., Jones, D., Eisman, G., Strong, A., Kren, R., Dillner, D., Round, R., Geer, I., McManus, D., and Murphree, T., "The Maury Project: A Three-Year Update," *Proceedings of the Sixth Symposium on Education at the Annual Meeting of American Meteorological Society*, Long Beach, CA, January 1997.

**CONFERENCE PRESENTATIONS:**

Murphree, T., "Predicting the Impacts of El Niño Events," Fall Meeting of the American Geophysical Union, San Francisco, CA, December 1997.

Smith, D., Guth, P., Viera, M., Whitford, D., Jones, D., Eisman, G., Strong, A., Kren, R., Dillner, D., Round, R., Geer, I., McManus, D., and Murphree, T., "The Maury Project: A Three-Year Update," Sixth Symposium on Education at the Annual Meeting of American Meteorological Society, Long Beach, CA, January 1997.

Smith, D., Saltzman, J., Viera, M., Whitford, D., Wright, W., Robichaud, R., Geer, I., McManus, D., and Murphree, T., "The Maury Project: A Look to the Future," Second Conference on Coastal Processes and Prediction and the Seventh Symposium on Education at the Annual Meeting of American Meteorological Society, Phoenix, AZ, January 1998, to be presented.

**DoD KEY TECHNOLOGY AREAS:** Other (Environmental Effects, Environmental Processes, Environmental Monitoring, Environmental Modeling)

**KEYWORDS**: Physical Oceanography, Pre-College Science Education

## MARINE ADVANCED TECHNOLOGY EDUCATION PROJECT

**Tom Murphree, Research Assistant Professor**
**Department of Meteorology**
**Sponsor: National Science Foundation**

**OBJECTIVES:** The is a new project to develop and implement a national program in marine advanced technology education.

**SUMMARY:** This project is part of a larger national project, the Marine Advanced Technology Education (MATE) Center, based at Monterey Peninsula College in Monterey, CA with the Naval Postgraduate School (NPS) being one of several partner institutions from around the country. The MATE Center began operating in September 1997 with funding from the National Science Foundation. The Center is designed to develop and coordinate a national program for marine science, engineering, and technology education involving high schools, technical schools, community and four-year colleges, graduate schools, military schools, and industry schools. The Center emphasizes intensive interactions between educational institutions and industry, military, government, and labor organizations.

In the NPS portion of the project, initial work has been completed to: (1) set up the national center's master plan, infrastructure, and staffing; (2) develop and coordinate collaborations between four-year colleges, graduate schools, and research organizations; (3) develop and coordinate collaborations with the U.S. Navy and Coast Guard; and (4) develop curricula, especially in the physical aspects of oceanography. One of the collaborations being pursued with the U.S. Navy is the development of a new curriculum for the Navy's oceanographic and atmospheric technicians who are educated at the Navy's meteorology and oceanography (METOC) A School.

**PUBLICATION:**

Crane, N., Matray, K., Murphree, T., Sullivan, D., Robertson, V., and Stewart, B., "Critical Issues in Marine Advanced Technology Education: A Report From a National Forum," National Science Foundation, Heritage Press, 51 pp., 1997.

**CONFERENCE PRESENTATION:**

Crane, N., Sullivan, D., Cook, S., Matray, K., Murphree, T., Robertson, V., and Kelly, V., "Developing an Infrastructure for Marine Technology Education," Annual Meeting of the American Association of Underwater Sciences, Alexandria, VA, September 1997.

**DoD KEY TECHNOLOGY AREAS**: Other (Environmental Processes, Environmental Monitoring, Environmental Modeling)

**KEYWORDS**: Marine Technology, Science and Engineering Education

## REAL-TIME ENVIRONMENTAL INFORMATION NETWORK AND ANALYSIS SYSTEM (REINAS)

**Wendell A. Nuss, Associate Professor**
**Department of Meteorology**
**Sponsor: Office of Naval Research and University of California, Santa Cruz**

**OBJECTIVE:** The objective of this research is to develop a mesoscale observing network and real-time data assimilation system for the Monterey Bay region and assist University of California, Santa Cruz develop computer database and visualization tools.

**SUMMARY:** This is an ongoing project and during 1997 the Naval Postgraduate School contribution to this joint research effort has focused on developing REINAS into a quasi-operational system and utilizing it for scientific studies. The database breadth was extended by adding the California Irrigation Management Service (CIMIS) stations to REINAS. The addition of these stations puts the number of surface observing sites cataloged in REINAS near 200. Work continues through the collaborations in the Bay Area Mesonet Initiative (BAMI) to expand the sites going into REINAS. Both the Monterey Bay and San Francisco Bay area air pollution agencies are now feeding data into the REINAS system. Three-dimensional multiquadric interpolation-based data assimilation system was implemented to routinely perform local mesonet analyses and is used to start the NPS MM5 real-time model runs for California. The three dimensional multiquadric interpolation approach to data assimilation has demonstrated the need to analyze the surface observations in complex topography in three dimensions. Previous analysis using two dimensional analysis approaches produced unrealistic thermal and wind analyses in the complex mesoscale topography. The three dimensional approach correctly analyzes the horizontal and vertical thermal structure in the boundary layer with observations distributed over the topography in the domain. These results show promise to allow surface observations to have a more substantial impact on model forecasts, at least in the short ranges (12-24 hours).

The local mesoscale analyses have been used in studies of the Monterey Bay sea breeze and its relationship to the synoptic-scale flow, which are nearly complete and a paper is in progress describing these results. A thorough analysis of the June 1996 time period has shown that identifiable differences in the horizontal and vertical structure of the circulation over the Monterey Bay occur under different synoptic regimes. Last year it was reported that differences for onshore and offshore directed synoptic-scale flows were seen in the sea breeze intensity and tendency for horizontal circulations within the Monterey Bay region. These differences were strongly related to the depth of the marine layer and its impact on the surface heating. Horizontal differences have also been found which relate to the interaction of the complex topography and the surface heating. These results are being written up in a paper. Although the thermally forced circulations are easily understood from a theoretical standpoint, the results of this study suggest that the interaction of many factors is critical in understanding the detailed flows in a complex coastal environment.

**PUBLICATIONS:**

Baskett, R.L., Lee, R.L., Nuss, W.A., Bornstein, R.D., Reynolds, D.W., Umeda, T., and Ludwig, F.L. "The Bay Area Mesonet Initiative (BAMI): A Cooperative Effort to Develop and Operate a Real-Time Mesonet in the Greater San Francisco and Monterey Bay Areas," *Preprints of the Symposium on Integrated Observing Systems,* Phoenix, AZ, January 1998.

Nuss, W.A., "The Real-Time Information and Analysis System (REINAS): A Scalable, Mesoscale Observing and Data Management System," *Preprints of the 14th Conference on Interactive and Image Processing Systems for Meteorology, Oceanography, and Hydrology*, Phoenix, AZ, January 1998.

Nuss, W.A., "The Real-Time Information and Analysis System (REINAS): A System to Support Mesoscale Forecasting," *Preprint of the Pacific Coast Forecast System Workshop*, Monterey, CA, August 1997.

Vesecky, J.F., Ludwign, F.L., Teague, C.C., Nuss, W.A., Onstott, R.G., Hansen, P., Fernandez, D. Daida, J., and Fischer, K., "Estimating the Surface Wind Field over Coastal Oceans Using Multi-Frequency, High Frequency Radar and In-Situ Observations," *Preprints in the Second Conference on Coastal Atmospheric and Oceanic Prediction and Processes*, Phoenix, AZ, January 1998.

**CONFERENCE PRESENTATIONS:**

Baskett, R.L., Lee, R.L., Nuss, W.A., Bornstein, R.D., Reynolds, D.W., Umeda, T., and Ludwig, F.L., "The Bay Area Mesonet Initiative (BAMI): A Cooperative Effort to Develop and Operate a Real-Time Mesonet in the Greater San Francisco and Monterey Bay Areas," Symposium on Integrated Observing Systems, Phoenix, AZ, January 1998, to be presented.

Nuss, W.A., "The Real-Time Information and Analysis System (REINAS): A Scalable, Mesoscale Observing and Data Management System," 14th Conference on Interactive and Image Processing Systems for Meteorology, Oceanography, and Hydrology, Phoenix, AZ, January 1998, to be presented.

Nuss, W.A., "The Real-Time Information and Analysis System (REINAS): A System to Support Mesoscale Forecasting," Pacific Coast Forecast System Workshop, Monterey, CA, August 1997.

Vesecky, J.F., Ludwig, F.L., Teague, C.C., Nuss, W.A., Onstott, R.G., Hansen, P., Fernandez, D., Daida, J., and Fischer, K., "Estimating the Surface Wind Field over Coastal Oceans Using Multi-Frequency, High Frequency Radar and In-Situ Observations," Second Conference on Coastal Atmospheric and Oceanic Prediction and Processes, Phoenix, January 1998, to be presented.

**DoD KEY TECHNOLOGY AREA:** Battlespace Environments

**KEYWORDS:** Coastal Meteorology, Data Management, Coastal Observing Network

## MESOSCALE COASTALLY-TRAPPED RESPONSE TO SYNOPTIC-SCALE VARIABILITY

**Wendell A. Nuss, Associate Professor**
**Department of Meteorology**
**Sponsor: Office of Naval Research**

**OBJECTIVE:** The primary long-term goal of this ongoing project is to understand the role that synoptic-scale circulations play in the generation, propagation, and decay of coastally-trapped disturbances. Additional goals are to understand the interaction of large-scale flows with coastal topography and the nature of the mesoscale response on the lee and windward sides of the topography, as well as to improve the forecasting of the mesoscale structure based upon the large-scale circulation.

**SUMMARY:** This is an ongoing project and the primary tasks completed in 1997 have been related to the analysis of observations collected during the summer 1996 field program. These observations and other routine observations have been used to re-analyze the summer 1996 stratus surge events plus selected coastal jet periods. Mesoscale surface analyses and synoptic-scale analyses of the upper-levels is being carried out for all wind reversal cases from 1996 and is nearly complete. These analyses include all available experimental data and will be used for diagnostic studies. In addition to the processing of the 1996 field program cases, the classification of wind reversal cases from 1994-1996 has been completed and enhanced during 1997.

During 1997, the boundary layer characteristics associated with these events have been added to the classifications using the NPS 915 MHZ profiler. As reported last year, the events clearly stratify into propagating and non-propagating

events. The propagating events are all characterized by an offshore directed cross-coast wind component while the non-propagating events have offshore flow only to the north of the disturbance. The significant addition to this finding during the past year has been to show that the boundary layer structure at Monterey is generally very consistent with this basic synoptic-scale forcing. The marine layer depths are characteristically much lower for propagating than non-propagating events. Furthermore, the propagating events were found to have an 850 mb height gradient opposite to the surface pressure gradient indicating the importance of the marine layer in reversing the coastal pressure gradient in propagating disturbances. Non-propagating events tended to have 850 mb height gradients in the same sense as the surface pressure gradient suggesting that the structure above the marine layer is sufficient to force southerly surface flows.

A study of the synoptic-scale relationships to the occurrence of a coastal jet near Pt. Sur was also done in 1997. This study utilized the NCEP Eta model and observations from buoy 46028 to relate wind speed at buoy 28 to synoptic-scale pressure gradient orientation. The basic hypothesis was that the coastal jet is related more to the along-coast pressure gradient than the geostrophic cross-coast pressure gradient. A key result from the coastal jet study (Stevens) near Pt. Sur was that the synoptic-scale pressure gradient orientation was relatively important in explaining the occurrence of high winds. The buoy winds were higher than the model winds by 7-8 m/s, which was the observed mean wind speed. This indicated the inability of the synoptic scale data assimilation to account for these coastal winds. Interestingly, the coastal jet was most pronounced when the geostrophic flow was primarily offshore (along-shore pressure gradient), which suggests that topographic trapping is important in the coastal jet formation. These results are being examined more closely in an ongoing analysis of the observations.

**PUBLICATIONS:**

Dorman, C.E., Rogers, D.P., Nuss, W.A., and Thompson, W., "Adjustment of the Summer Marine Boundary Layer Around Pt Sur, California," *Monthly Weather Review,* 1998, submitted.

Nuss, W.A., "Synoptic-Scale Structure and the Character of Coastally Trapped Disturbances," *Preprints of the Second Conference on Coastal Atmospheric and Ocean Prediction and Processes*, Phoenix, AZ, January 1998.

Miller, D. and Nuss, W.A., "Classification and Numerical Simulation of California Coastal Surges," *Preprints of the Second Conference on Coastal Atmospheric and Ocean Prediction and Processes*, Phoenix, AZ, January 1998.

Ralph, F.M., Armi, L., Bane, J.M., Dorman, C., Neff, W.D., Neiman, P.J., Nuss, W.A. and Persson, P.O.G., "Observations and Analysis of 10-11 June 1994 Coastally Trapped Disturbance," *Monthly Weather Review,* 1998, accepted.

Rogers, D.P., Dorman, C.E., Edwards, K., Brooks, I., Melville, K., Burk, S., Thompson, W., Holt, T. Strom, L., Tjernstrom, M., Grisogono, B., Bane, J., Nuss, W.A., Morley, B., and Schanot, A., "Highlights of Coastal Waves 1996," *Bulletin of the American Meteorology Society,* 1998, accepted.

**CONFERENCE PRESENTATIONS**:

Nuss, W.A., "Synoptic-Scale Structure and the Character of Coastally Trapped Disturbances," Second Conference on Coastal Atmospheric and Ocean Prediction and Processes, Phoenix, AZ, January 1998, to be presented.

Miller, D. and Nuss, W.A., "Classification and Numerical Simulation of California Coastal Surges," Second Conference on Coastal Atmospheric and Ocean Prediction and Processes, Phoenix, AZ, January 1998, to be presented.

**THESIS DIRECTED:**

Stevens, R.S., "Sensitivity of the California Coastal Jet to Synoptic Scale Flow," Master's Thesis, Naval Postgraduate School, September 1997.

**DoD KEY TECHNOLOGY AREAS:** Battlespace Environments

**KEYWORDS:** Coastal Meteorology, Coastal Forecasting, Coastal Observations

### EVALUATION OF SATELLITE-DERIVED INFORMATION AS AN ANALYSIS TOOL AND TO IMPROVE PREDICTABILITY OVER CONVENTIONAL DATA-SPARSE REGIONS

**Wendell A. Nuss, Associate Professor**
**Douglas K. Miller, Research Assistant Professor**
**Department of Meteorology**
**Sponsor: Office of Naval Research**

**OBJECTIVE:** The long-term goal of this project is to develop a method to assimilate satellite observations into a mesoscale model to improve prediction in data sparse regions. The objectives of this research are to assimilate satellite cloud drift winds, satellite soundings, and irradiances into a mesoscale model using multiquadric interpolation. The system will be tested using data obtained during FASTEX and validation tests done to demonstrate its capability.

**SUMMARY:** This is the early stages of the project and so only limited tasks have been completed. To date these include getting the MM5 model running routinely with the multiquadric data assimilation system. Cases from FASTEX have been selected in collaboration with Chris Velden, University of Wisconsin. Satellite data sets have been obtained from Chris Velden and software to read these data sets has been written.

**DoD KEY TECHNOLOGY AREAS:** Battlespace Environments

**KEYWORDS:** Marine Meteorology, Numerical Forecasting, Data Assimilation

### CASE STUDIES OF THE ABILITY OF THE NAVY'S MESOSCALE DATA ASSIMILATION SYSTEM TO DEPICT MESOSCALE PHENOMENA

**Patricia M. Pauley, Research Associate Professor**
**Department of Meteorology**
**Sponsor: Naval Research Laboratory**

**OBJECTIVE:** The goal of this research is to examine the performance of the Navy's mesoscale data assimilation system for cases with strong mesoscale forcing. Features such as jet streaks and upper fronts stretch the limits of the capability of the data assimilation system, but are important weather producers and therefore should be both analyzed and predicted. This was the third year of a three-year project.

**SUMMARY:** The work performed during calendar year 1997 involved preparing publications and writing computer code. In association with a thesis student, a comparison of methods used to compute sea-level pressure from either station or model data was completed and has been accepted for publication in *Weather and Forecasting*. This work was motivated by difficulties in preparing manual analyses to be used in verifying surface features associated with upper fronts. Two preprint articles were also prepared detailing thesis work undertaken by two other students. One presented a case study from April 1997 using COAMPS analyses. The other summarized results from a two-month comparison of aircraft observations and NORAPS analyses for upper front cases. Quality control software that was developed as part of the latter effort is being transitioned to operational use at NRL, as is the COAMPS diagnostic code that was used in the thesis research.

**PUBLICATIONS:**

Pauley, P.M., "An Example of Uncertainty in Sea Level Pressure Reduction," *Weather and Forecasting*, 1998, accepted.

Pauley, P.M. and Stephens, E.L., "A Comparison of Upper Front Strength as Analyzed by NORAPS and as Observed by ACARS-Equipped Aircraft," *Preprints of the 16th Conference on Weather Analysis and Forecasting*, pp. 95-97, Phoenix, AZ, 11-16 January 1998.

Schwingshakl, K.J. and Pauley, P.M., "A Case Study of Strong Surface Winds Associated with an Upper Front Using the COAMPS Data Assimilation System," *Preprints of the 16th Conference on Weather Analysis and Forecasting*, pp. 92-94, Phoenix, AZ, 11-16 January 1998.

**CONFERENCE PRESENTATIONS:**

Pauley, P.M. and Stephens, E.L., "A Comparison of Upper Front Strength as Analyzed by NORAPS and as Observed by ACARS-Equipped Aircraft," 16th Conference on Weather Analysis and Forecasting, Phoenix, AZ, 11-16 January 1998.

Schwingshakl, K.J. and Pauley, P.M., "A Case Study of Strong Surface Winds Associated with an Upper Front Using the COAMPS Data Assimilation System," 16th Conference on Weather Analysis and Forecasting, Phoenix, AZ, 11-16 January 1998.

**THESES DIRECTED:**

Burke, S.T., "A Case Study of High Winds Induced by Upper-Level Frontogenesis and Tropopause Folding," Master's Thesis, Naval Postgraduate School, March 1997.

Schwingshakl, K.J., "Investigation of Strong Surface Winds Associated with an Upper Front Using COAMPS," Master's Thesis, Naval Postgraduate School, September 1997.

Stephens, E.L., "A Comparison of Upper Front Strength as Analyzed by NORAPS and as Observed by ACARS-Equipped Aircraft," Master's Thesis, Naval Postgraduate School, September 1997.

**OTHER:**

Computer code that reads in COAMPS fields and performs a variety of diagnostic quantities was modified by the PI from a previous version that read in NORAPS fields for use in the thesis research by LCDR Ken Schwingshakl and has been implemented at NRL as part of the COAMPS suite. In addition, the aircraft quality control code that was developed by the PI for use in the thesis research by LT Ed Stephens is currently being implemented as part of the 3-D variational objective analysis system at NRL.

**DoD KEY TECHNOLOGY AREA:** Other (Environmental Effects)

**KEYWORDS:** Data Assimilation, Jet Streak, Upper Front, Aircraft Observations

## TROPICAL CYCLONE MOTION STUDIES

**Elizabeth A. Ritchie, Research Assistant Professor**
**Russell L. Elsberry, Professor**
**Patrick A. Harr, Research Assistant Professor**
**Department of Meteorology**
**Sponsor: Office of Naval Research**

**OBJECTIVE:** As a tropical cyclone interacts with the environment, asymmetries develop that directly affect the motion and intensity of the storm. The objective of this portion of the continuing project is to study interactions with convective asymmetries that have been hypothesized to impact the development, structure, and motion of tropical cyclones, with

baroclinic environments within the tropics and in the midlatitudes during extratropical transition, and with topography as a tropical storm makes landfall.

**SUMMARY:** The motion and structural development of tropical cyclones in a baroclinic vertical shear environment has been numerically simulated using a high resolution, mesoscale model (MM5). Important results include the identification of persistent patterns of asymmetric convection and rainfall in the front-left quadrant of the storm rather than the front-right predicted by corresponding dry simulations. The first-order structural changes in the core of a tropical cyclone due to persistent asymmetric convection have also been studied. It was found that the rate of intensification of a tropical cyclone with asymmetric convection was slower than that for a symmetrically forced tropical cyclone. However with time, the same maximum intensity was attained.

A case study of a transitioning typhoon over Japan has been run using the Coupled Ocean-Atmosphere Mesoscale Prediction System (COAMPS) from the Naval Research Laboratory-Monterey. Although the predicted storm motion was slow for the COAMPS simulation, the path was very close to that observed, and rainfall patterns closely matched the SSM/I data. In general, the COAMPS system appeared to have captured the main aspects of the extratropical transition as well as complex topographical interactions as the typhoon interacted with the high terrain.

**PUBLICATIONS:**

Frank, W.M. and Ritchie, E.A., "Environmental Effects on the Structure of Tropical Storms," *Proceedings of the 22nd Conference on Hurricanes and Tropical Meteorology,* pp. 352-353, American Meteorology Society, Boston, MA, 1997.

Ritchie, E.A. and Frank, W.M., "Effects of Convective Asymmetries on the Structure of Tropical Storms," *Proceedings of the 22nd Conference on Hurricanes and Tropical Meteorology*, pp. 199-200, American Meteorology Society, Boston, MA, 1997.

**CONFERENCE PRESENTATIONS:**

Ritchie, E.A., "Tropical Cyclone-PV Anomaly Interactions," Workshop on Tropical Cyclone - Trough Interactions," Bad Tolz, Germany, 4-8 August 1997.

Ritchie, E.A., Harr, A., and Elsberry, R.L., "A Study of the Development of Mesoscale Asymmetries in Tropical Cyclone Structure during Landfall," The 12th Conference on Numerical Weather Prediction, Phoenix, AZ, 11-16 January 1998.

**DoD KEY TECHNOLOGY AREAS:** Environmental Quality, Modeling and Simulation

**KEYWORDS:** Tropical Cyclones, Mesoscale Modeling

## ANALYSES OF AIRCRAFT MEASUREMENTS OF THE STABLE BOUNDARY LAYERS IN THE ARCTIC

**Qing Wang, Assistant Professor**
**Department of Meteorology**
**Sponsor: National Aeronautics and Space Administration-Langley**

**OBJECTIVE:** The objective of this project is to understand the length scales controlling the turbulence transport over the Arctic Oceans. The goal is to construct optimal strategies for improved measurements in FIRE-III/SHEBA.

**SUMMARY**: Aircraft measurements on boundary layer turbulence structure were made by the NCAR C-130 during the Beaufort Arctic Storms Experiment (BASE) in 1994. Data from three flights during the BASE experiment have been analyzed to study the characteristics of the stable Arctic boundary layer that is usually characterized by weak turbulent mixing and significant wave and mesoscale perturbations. Spectral analyses have been performed for all leveled legs in the selected flights. Turbulence variance and fluxes were then obtained from the spectra and co-spectra. In general, very weak

turbulence field in the fall season Arctic boundary layer were found, which is reflected in the variances of momentum, temperature, and water vapor (when available). Buoyancy flux was in general negative, consistent with the stable stratification. Also examined was the turbulence length scale for the first and second moment variables in the stable boundary layer. Our results indicate that the integral scale for the second-moment variables, such as fluxes and variances, are smaller than those for the mean variables. However, the second-moment variables have much larger spatial variation, suggesting that a much longer measurement length is needed in order to obtain statistically significant results. Further comparison of the results with those from the convective boundary layer is currently underway.

**PUBLICATION:**

Paluch, I.R., Lenschow, D.H., and Wang, Q., "The Arctic Boundary Layer in the Fall Season over Open and Frozen Sea," *Journal of Geophysical Research*, 120, pp. 25,955-25,971, 1997.

**DoD KEY TECHNOLOGY AREA:** Environmental Quality

**KEYWORDS:** Boundary Layer Meteorology, Turbulence Structure

## CHARACTERISTICS OF THE MARINE BOUNDARY LAYER DURING AEROSOL CHARACTERIZATION EXPERIMENT (ACE-1)

**Qing Wang, Assistant Professor**
**Department of Meteorology**
**Sponsors: National Science Foundation and Naval Postgraduate School**

**OBJECTIVE:** The objective of this project is to study mechanisms for turbulent mixing in the marine boundary layer. The goal is to examine the effects of boundary layer dynamics in determining the chemical and physical properties of atmospheric aerosols.

**SUMMARY:** This project focuses on the boundary layer dynamics that have profound effects on aerosol mixing and evolution in marine boundary layers. The measurements were made during the Southern Hemisphere Aerosol Characterization Experiment (ACE-1). The particular data sets used here were from the Lagrangian measurements where an instrumented aircraft followed the same air column for three days. The evolution of the boundary layer turbulence characteristics and entrainment mixing across the interface between the marine boundary layer and the troposphere or the buffer layer has been studied. From the previous year's research, it was found that the boundary layer was separated into two layers. The lower layer was characterized by shear generated turbulence, while the upper layer had weak stable stratification with weak and intermittent turbulence fields. Layering of aerosols was also evident in the upper boundary layer, called the buffer layer. In 1997, the characteristics of turbulent mixing were further examined through detailed data analysis. The focus was on the horizontal variability of turbulence mixing due to variations in sea surface temperature. Boundary layer structure was examined separately for regions where surface shear and buoyancy forcing played significantly different roles. The role of cloud in entrainment mixing was also analyzed.

**PUBLICATIONS:**

Suhre, K., Mari, C., Bates, T.S., Johnson, J.E., Rosset, R., Wang, Q., Bandy, A.R., Blake, D.R., Eisele, F.L., Kok, G.L., Mauldin, R.L., III, Prévot, A., Schillawski, R.D., and Thornton, D.C "Physico-Chemical Modeling of ACE-1 Lagrangian #B. 1. A Moving Column Approach," *Journal of Geophysical Research*, 1997, accepted.

Wang, Q. and Pan, L., "Boundary Layer Evolution in Response to Variations of Sea Surface Temperature and Wind Shear," *Preprints of the 12th Symposium on Boundary Layers and Turbulence*, pp. 34-35, American Meteorological Society, Vancouver, Canada, 28 July-1 August 1997.

**CONFERENCE PRESENTATION**:

Wang, Q. and Pan, L., "Boundary Layer Evolution in Response to Variations of Sea Surface Temperature and Wind Shear," 12th Symposium on Boundary Layers and Turbulence, American Meteorological Society, Vancouver, Canada, 28 July-1 August 1997.

**DoD KEY TECHNOLOGY AREA**: Environmental Quality

**KEYWORDS:** Boundary Layer Measurements, Entrainment, Aerosol Study

## OBSERVATIONS AND DATA ANALYSIS OF THE MARINE BOUNDARY LAYER AND CLOUD DURING THE AEROSOL CHARACTERIZATION EXPERIMENTS (ACE)

**Qing Wang, Assistant Professor**
**Philip A. Durkee, Professor**
**Department of Meteorology**
**Sponsor: National Science Foundation**

**OBJECTIVE:** The objectives of this study were to understand the role of boundary layer turbulence in aerosol and cloud evolution from observational data. A secondary objective of this first year effort is to implement and evaluate a measurement system designed to measure turbulence perturbations of air velocity and temperature. The goal is to understand the indirect effects of marine and anthropogenic aerosols in regulating global radiation and to establish a turbulence measurement and data reduction system for the Center for Interdisciplinary Remotely-Piloted Aircraft Studies (CIRPAS) at NPS.

**SUMMARY:** 1997 was the first year of this NSF sponsored project. This study involved observations from both ACE-1 and ACE-2 experiments. The work on ACE-1 has been summarized in a previous summary (listed as sponsored by NSF and NPS). Major efforts for the ACE-2 experiment in this first year include: (1) Instrument evaluation for preparation of the field measurement. The set of instrument investigated include a differential pressure sensing system built by NOAA ATDD for true air velocity, flow angle, and high-frequency attitude angle measurements, a differential GPS system for aircraft velocity measurements, and a separate GPS system for attitude angle measurements. Potential effects of the flow distortion on turbulence and aerosol measurements were also evaluated. (2) Participation in the field measurement in ACE-2. Involvement was in both flight planning and on-site preliminary data analysis. On-site data analysis proved to be helpful since it was the first step in data quality checking. (3) Development of techniques for turbulence data reduction from the unique measurement system on the CIRPAS Pelican. Considerable work has been done in algorithm development for the data reduction. Preliminary results will be presented at the ACE-2 Pelican data workshop in early 1998.

**PUBLICATIONS:**

Wang, Q., Suhre, K., Krummel, P., Siems, S., Pan, L., Bates, T.S., Johnson, J.E., Lenschow, D.H. Heubert, B., Kok, G.L., Schillawski, R.D., Prévot, A., and Businger, S., "Characteristics of the Marine Boundary Layers during Two Lagrangian Measurement Periods. Part I: General Conditions and Mean Characteristics," *Journal of Geophysical Research,* 1997, submitted.

Wang, Q., Lenschow, D.H., Pan, L., Schillawski, R.D., Kok, G.L., Prévot, A.S.H. Laursen, K., Russell, L.M., Bandy, A., Thornton, D., and Suhre, K., "Characteristics of the Marine Boundary Layers during Two Lagrangian Measurement Periods Part II: Turbulence Structure," *Journal of Geophysical Research,* 1997, submitted.

**DoD KEY TECHNOLOGY AREA:** Environmental Quality

**KEYWORDS:** Boundary Layer Measurements, Aerosol-Cloud Interaction

### NUMERICAL MODELING OF TURBULENCE-AEROSOL-CLOUD INTERACTION

**Qing Wang, Assistant Professor**
**Department of Meteorology**
**Sponsor: Naval Research Laboratory**

**OBJECTIVE:** The objective for this project is to understand the interaction between turbulence, atmospheric aerosols, and marine stratocumulus clouds. The feasibility of incorporating size-resolved aerosol and cloud microphysics into a mesoscale model, such as COAMPS, will also be evaluated based on sensitivity of results from the current 1-D model on choice of the number and width of bins for aerosol and clouds.

**SUMMARY:** This study is a modeling effort to address the indirect radiative effect of aerosol, i.e., its interaction with low-level clouds. Results from past 1-D models with explicit aerosol and cloud microphysics have shown significant discrepancies from results from large eddy simulations and/or observations. This was caused by unrealistic representation of aerosol activation and droplet growth processes. The first year's research on this project focused on model development and testing. The coupling of a 1-dimensional third-order turbulence closure model with a size resolved aerosol and cloud microphysics model has been finished. Initial testing of the new coupled model has been performed using initial condition from GCSS model comparison workshop. Although aerosol activation and droplet growth in the current model are still forced by the mean supersaturation, a full coupling has been incorporated between aerosol-cloud microphysics and the boundary layer dynamics, which is a significant improvement from existing 1-D models of similar nature. Preliminary results will be presented at the ONR/NRL annual review (1997) at Monterey, CA, in early February 1998. More in-depth study is underway to incorporate special schemes to account for activation and droplet growth in turbulent updrafts and downdrafts.

**DoD KEY TECHNOLOGY AREA:** Environmental Quality

**KEYWORDS:** Boundary Layer Modeling, Aerosol-Cloud Interaction

### COLLABORATIVE RESEARCH PROJECTS IN DIRECT SUPPORT OF FLEET NUMERICAL METEOROLOGY AND OCEANOGRAPHY CENTER (FNMOC) OPERATIONAL MISSION

**Carlyle H. Wash, Professor**
**Department of Meteorology**
**Sponsor: Office of Naval Research**

**OBJECTIVE**: The broad objective of this research is to execute collaborative research projects with the Fleet Numerical Meteorology and Oceanography Center (FNMOC). The collaboration includes NPS Meteorology faculty, NPS students conducting thesis research, and FNMOC personnel. These joint projects address FNMOC operational needs and advance the understanding of marine meteorology.

**SUMMARY**: Two collaborative thesis projects were supported in FY97 funding. The first project is: "Evaluation of FNMOC Scatterometer Derived Winds," by LCDR John Whalen, USN. NPS thesis advisor is Professor Kenneth Davidson and FNMOC collaborator is Chuck Skupniewicz. In this study, the scatterometer wind product from FNMOC is evaluated by in-situ winds obtained continuously from specially instrumented AEGIS cruisers.

The second project is: "An NWP-Perfect Prog Model for Selected Weather Elements," by LCDR Brian Bommarito, USN. NPS thesis advisor is Professor C.-P. Chang and FNOMC collaborator is Dr. Mary Alice Rennick. In this study, a prototype statistical forecast model is developed that uses NWP output to forecast weather elements such as ceiling height and probability of precipitation at particular locations.

**THESIS DIRECTED**:

Bommarito, B., "An NWP-Perfect Prog Model for Selected Weather Elements," Master's Thesis, Naval Postgraduate School, December 1997.

Whalen, J., "Evaluation of FNMOC Scatterometer Derived Winds," Master's Thesis, Naval Postgraduate School, December 1997.

**DoD KEY TECHNOLOGY AREAS**: Battlespace Environments

**KEYWORDS:** Operational Mission, Marine Meteorology, FNMOC Support

### DEVELOPMENT OF CLOUD FORECAST PRODUCTS FROM COUPLED OCEAN-ATMOSPHERE MESOSCALE PREDICTION SYSTEM (COMAPS)

**Carlyle H. Wash, Professor**
**Department of Meteorology**
**Sponsor: Naval Research Laboratory-Monterey**

**OBJECTIVE**: The objective of this effort is to develop a plan to produce cloud forecast products from the new NRL mesoscale model COAMPS, the Coupled Ocean-Atmosphere Mesoscale Prediction System. The plan includes a variety of cloud forecast products including cloud type and coverage, point cloud forecasts, and forecast of important aviation parameters.

**SUMMARY**: A research plan to develop cloud forecast products was developed during this project and was included in a major 6.2 new start proposal entitled, "Deriving Environmental Parameters for Flight Rehearsal and Planning." Support will be sought from the Defense Modeling and Simulation Office (DMSO).

**CONFERENCE PRESENTATION:**

Wash, C.H., "Validation of COAMPS Cloud Parameters," NRL/PL Model Applications Workshop, Monterey, CA, 11-12 March 1997.

**DoD KEY TECHNOLOGY AREA:** Modeling and Simulation

**KEYWORDS:** Cloud Forecasting, COAMPS, Mesoscale Modeling and Forecasting

### BOUNDARY LAYER EFFECTS ON MESOSCALE PHENOMENON

**Roger T. Williams, Professor**
**Department of Meteorology**
**Sponsor: Naval Research Laboratory**

**OBJECTIVE:** To improve the simulation of mesoscale phenomena over topography with boundary layer effects.

**SUMMARY:** The effect of surface friction on the mountain gravity wave was investigated using a two-dimensional version of the U.S. Navy's nonhydrostatic Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS). The effect of the surface friction was to reduce the amplitude and strength of the gravity wave activity on the lee side. It is hypothesized that the boundary layer acts as a quasi-material surface such that the flow encounters a mountain with a smoother slope on the upwind side and shallower height on the lee side. This hypothesis was verified using a simulation without surface friction in which the mountain profile was constructed by adding the PBL height from the control simulation to the terrain height. The flow generated in this simulation without surface friction was very similar to the flow in the control simulation, thus confirming the hypothesis. The results show that, as the terrain height increases, the boundary layer on the lee side is increasingly suppressed, indicating that the quasi-material surface becomes permeable to gravity wave energy for very steep mountains. This research was carried out in conjunction with Drs. M.S. Peng and W.T. Thompson of NRL-Monterey.

**PUBLICATION:**

Williams, R.T., Neves, A.P.C., Peng, M.S., and Blumen, W., "Unbalanced Frontogenesis with Constant Potential Vorticity," *Proceedings of the 11th American Meteorological Conference on Atmospheric and Oceanic Fluid Dynamics,* pp. 95-96, Tacoma, WA, 23-27 June 1997.

**CONFERENCE PRESENTATION**:

Williams, R.T., Neves, A.P.C., Peng, M.S., and Blumen, W., "Unbalanced Frontogenesis with Constant Potential Vorticity," 11th American Meteorological Conference on Atmospheric and Oceanic Fluid Dynamics, Tacoma, WA, 23-27 June 1997.

**DoD KEY TECHNOLOGY AREA:** Battlespace Environments

**KEYWORDS:** Numerical Models, Topographic Effects, Boundary Layer

## TROPICAL MONSOON-WAVE INTERACTIONS

**Roger T. Williams, Professor**
**C.-P. Chang, Professor**
**Department of Meteorology**
**Sponsors: National Science Foundation and Naval Postgraduate School**

**OBJECTIVE**: This is a continuing project to study nonlinear interactions between tropical monsoon circulation and equatorial wave disturbances in the western Pacific.

**SUMMARY**: A numerical study of tropical waves propagating from the central to the western Pacific was completed. The periodic forcing produced westward moving (short) Rossby waves, which were trapped at the longitude where the mean zonal wind changed from easterly to westerly. When the forcing was increased the waves became nonlinear and they no longer had a single frequency. These waves were also totally trapped at the latitude of zero zonal wind. In both cases the east-west wave scale decreased as the waves approached the critical longitude. These numerical solutions did not show much energy accumulation in the zone where the zonal flow reverses. Rather, there was an indication of energy dispersion in the meridional direction and also some evidence of energy damping. Thus it appears that the wave energy may feed into the mean flow. This is an important result which will be analyzed further in order to shed light on the behavior of the waves in the confluence zone.

A study on tropical cyclones in different uniform mean flows was started. Both the planetary vorticity gradient and a mean flow generated asymmetry in the cyclone and limited the development of the cyclone. The intensity of a storm was inversely proportional to the strength of the wavenumber-one asymmetry, which imposed the ventilation flow across the center. An intensifying cyclone was associated with a small wavenumber-one asymmetry that allowed a more symmetric distribution of the surface momentum and heat fluxes and low-level moisture convergence around the center. A large ventilation flow generated a large asymmetry in the surface fluxes and moisture convergence. Due to the orientation of the wavenumber-one circulation induced by the beta effect in a quiescent environment, ventilation in the asymmetric circulation induced by a westerly basic flow canceled part of the beta effect while an easterly flow added to the beta effect. Therefore, a westerly flow was more favorable for tropical cyclone development when the planetary vorticity gradient was present.

A further study of tropical cyclone dynamics concerned the observed rotation of the eye of Typhoon Herb (1996). An elliptical eye was documented which rotated cyclonically with a period of approximately 144 minutes in Typhoon Herb. Two complete periods of approximately 144 minutes were observed in the Doppler radar data. Both linear and nonlinear theories were presented to explain the observed eye rotation. The intensification of the strongest monsoon disturbance over the East China Sea in a seven-year period was studied using potential vorticity diagnostics. The diagnostic used linear and nonlinear balance equations and identified the roles of diabatic heating, tropopause folding, and boundary layer processes in the low-level vorticity intensification. Previous studies have all indicated the dominant role of diabatic heating in the disturbance development. The result shows that in this case it was a very strong tropopause folding, and a resulting deep

vertical coupling between three disturbances, at the lower, middle and upper troposphere respectively, that led to the strong intensification.

**PUBLICATIONS**:

Chang, C.-P. and Hou S., "The Development of A Mei-Yu Disturbance during East Asian Monsoon." *Proceedings of the First WMO International Workshop on Monsoon Studies*, pp. 19-22, World Meteorological Organization, Geneva, Switzerland, 1997.

Chang, C.-P., Hou, S., Kuo, H.-C., and Chen, G.T., "Vortex Development in the East Asian Monsoon due to Strong Vertical Coupling," *Monthly Weather Review*, 126, 1998, in press.

Jeng, B.-F., Peng, M.S., and Williams, R.T., "Effect of Asymmetric Structure on the Intensification of Tropical Cyclones," *Proceedings of the 22nd Conference on Hurricanes and Tropical Meteorology*, pp. 141-143. American Meteorological Society, Fort Collins, CO, 19-23 May 1997.

**CONFERENCE PRESENTATIONS**:

Chang, C.-P. and Hou, S.C., "The Development of A Mei-Yu Disturbance during East Asian Monsoon," First WMO International Workshop on Monsoon Studies, Denpasar, Indonesia, 24-28 February 1997.

Jeng, B.-F., Peng, M.S., and Williams, R.T., "Effect of Asymmetric Structure on the Intensification of Tropical Cyclones," 22nd Conference on Hurricanes and Tropical Meteorology, American Meteorological Society, Fort Collins, CO, 19-23 May 1997.

**DoD KEY TECHNOLOGY AREAS**: Other (Environmental Effects)

**KEYWORDS:** Tropical Meteorology, Monsoon, Tropical Cyclones, Tropical Waves